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VOL. 42 NO. 394 OCTOBER 1956

THE INSTITUTE OF PETROLEUM

AN Ordinary General Meeting of the Institute of Petroleum was held at 26 Portland Place, London, W.1, on 9 May 1956, the Chair being taken by T. Dewhurst, Past-President of the Institute.

The General Secretary read the minutes of the previous meeting, which were confirmed and signed as a correct record. He also announced the names of members elected since the previous meeting.

The Chairman introduced P. S. Hirtz, who presented the following paper in summary:

RECENT OIL DEVELOPMENT IN FRANCE*

By P. S. HIRTZ†

INTRODUCTION

History of Oil Exploration in France

The production of petroleum began in France a long time ago. In fact, since the fifteenth century, the oil brought to the surface by the spring of Pechelbronn, in Alsace, was gathered for different purposes. In the eighteenth century a mine was established in the neighbourhood of that spring. The end of the nineteenth century saw the beginning of drilling operations and the annual production reached nearly 150,000 brl. By 1920 the production attained 500,000 brl, and this figure has not been surpassed.

Some years later, a well drilled by the "Office National des Combustibles" led to the discovery of a second oilfield in Metropolitan France, at Gabian, in Languedoc. Yet its extension revealed itself to be very limited, as the total quantity of oil recovered did not exceed 200,000 brl.

On the eve of the second world war, the National Administration became disturbed by the backwardness of French petroleum production, which was and is a vital question for modern economy. A programme of exploration was established on a national scale in France and the French Union; and for that purpose, a "Centre de Recherches de Pétrole du Midi" was entrusted with the exploration of different areas and particularly the Aquitaine basin, which presented favourable possibilities.

The first well to be drilled, St Marcet No. 1, was located on a surface anticline, at the foot of the Pyrenees. By an exceptional chance, it discovered an important gas field, on 14 July 1939.

Unfortunately, during the war, exploration activity was considerably reduced.

After the end of the war the development of oil prospecting in France became urgent. This was due to the world consumption of petroleum, which reached a record high level. France, which was obliged to be supplied with crude oil almost exclusively by foreign countries, possessed numerous sedimentary basins, which had not yet been explored. The total area of these basins in France and the French Union amounts to approx 1,750,000 sq. miles, of which 115,000 sq. miles occur in Metropolitan France, *i.e.* nearly three-fifths of its total area.

In order to establish a programme of exploration and to assure its working in the exclusive interest of the nation, the Government created, towards the end of 1945, a "Bureau de Recherches de Pétrole," financed by State credits. The chief effort was concentrated in Metropolitan France, and particularly in the three zones where favourable results had already been obtained: the Aquitaine, the Alsace, and the Languedoc basins.

At a first examination the principal results obtained from the end of 1946 until the beginning of 1954 would seem to be of modest importance.

In fact, that period of the history of French oil exploration corresponds to a young or even embryonic phase. France can be compared with other countries where large oil reserves have been discovered, like Canada, for instance, at the same phase of their oil development. Such a comparison leads to a more optimistic appraisal of the results obtained in France.

In Aquitaine the St Marcet discovery was extended to the adjoining structure of St Martory, which has proved to be much less productive.

After a complete development of the St Marcet field, the annual production of gas was established at nearly 8800 million cu. ft, with 200,000 brl of condensate, the initial reserves reaching 230,000 million cu. ft.

On the other hand, in the western part of the basin, not far from Pau, an oilfield was discovered in 1949, on the buried structure of Lacq, by seismic prospecting. The initial reserves reached 17 million brl, and an annual production was established after the complete development of the field, at about 2,000,000 brl.

At the end of 1951 a deeper gas pool was discovered at a depth of 11,500 ft. The gas was sulphurous, and under a strong pressure, which produced a violent blow-out. The development of this new pool was immediately begun under conditions rendered very severe by the depth, the pressure, and gas corrosion.

In Alsace, in the neighbourhood of the Pechelbronn oilfield, which was nearly depleted, further attempts to discover oil accumulations were practically negative.

* MS received 7 February 1956.

† Bureau de Recherches de Pétrole, Paris.

Local discoveries, sometimes promising, remained without a real future. In the meridional part of the basin a wildcat drilled in Staffelfelden, near Mulhouse, in search of potash, discovered a small oilfield. Its maximum production did not exceed 750 b.d., and its initial reserves reached only 450,000 brl.

At Gallician, in the Camargue, approx 20,000 brl of oil were discovered, but elsewhere in the Languedoc there was no amount of commercial significance. Nor in other parts of France did the drilling reveal anything of commercial interest.

Finally, the results of the exploration, which lasted seven years, were the discoveries of:

One gas pool of an undetermined importance.
One oil pool of the " C " group.*
One oil pool of the " E " group.*

In March 1954 a new and important discovery was made in the western part of the Aquitaine basin at

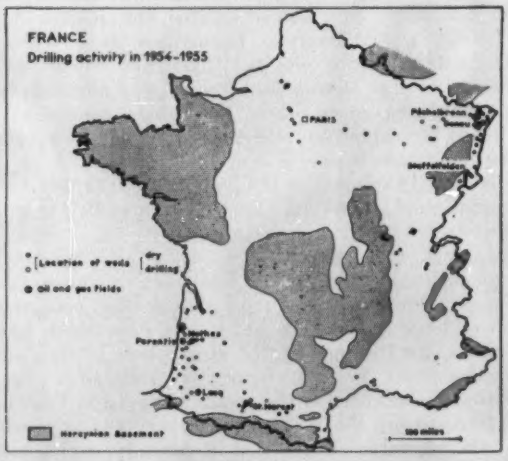

FIG 1

Parentis. This time it was an oilfield of the " A " group. It is not surprising that this discovery was of considerable interest at that time, especially as in the U.S.A. only three " A " fields were discovered in 1948, four in 1951, and, as far as is known, none in 1953.

Therefore, in the history of French petroleum, the year 1954 marked the beginning of an era of increased activity (Fig 1).

Towards the end of 1955 the exploration permits granted covered 53,500 sq. miles, *i.e.* approx 44 per cent of the total area of the French sedimentary basins. Meanwhile twenty-three applications were made for new permits, often in competition and covering 20 per cent of the same area (Fig 2).

The results obtained since the beginning of this increased activity are the essential object of the statements which follow. These results will be placed in a

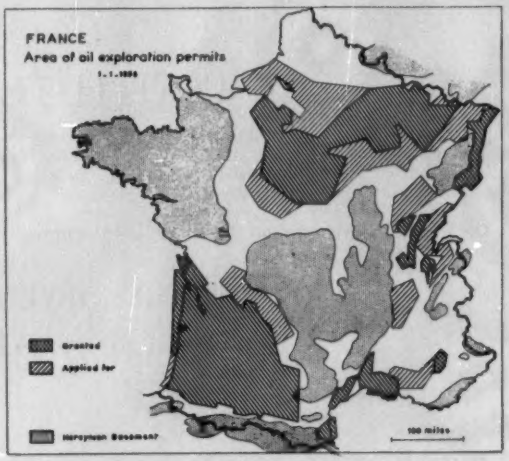

FIG 2

geological and historical frame, which will ensure their better comprehension.

SUMMARY GLANCE AT THE GEOLOGICAL STRUCTURE OF FRANCE (Fig 3)

The architecture of the French soil is determined by structural elements of three types:

(1) *Ancient Massifs.* These are regions constituted by Paleozoic formations, which have been affected by the Hercynian orogeny. Since that time these areas remained rigid zones. The Paleozoic is there sometimes metamorphosed. Coal basins are found inside these massifs or on their margins.

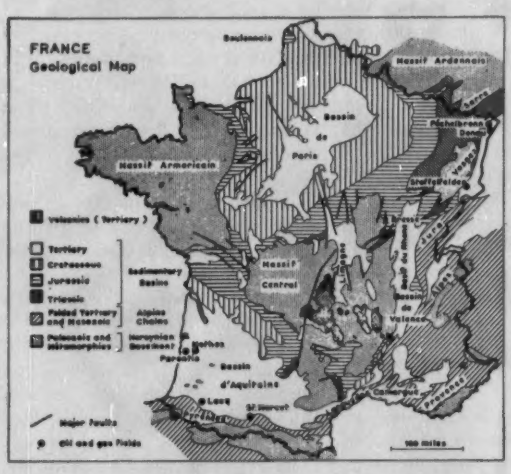

FIG 3

* International classification of Lahee:

A = 50 million brl or more;
B = between 25 and 50 million brl;
C = between 10 and 25 million brl;
D = between 1 and 10 million brl;
E = less than 1 million brl.

(2) *Folded Chains of Alpine Age.* These have been formed mostly during the Tertiary, and they are composed of great thicknesses of Mesozoic and Tertiary formations. The Alps form a chain of the geosynclinal type. In front of them the Jura and the chains of Provence correspond to a *chaine de couverture* and the Pyrenees constitute a *chaine de revêtement.*

(3) *Basins*, generally of a simple structure, which set apart the ancient massifs and the folded chains. They are of two types: (*a*) depositional basins subsequent to the Hercynian orogeny, and the filling of which is, moreover, essentially of Mesozoic and Tertiary age; and (*b*) grabens which were formed during Oligocene time, inside the Hercynian massifs, as a counter stroke to the Alpine foldings.

In order to determine the geological frame of French petroleum exploration, the different units corresponding to these three structural types will be rapidly examined.

THE ANCIENT MASSIFS

The Armorican Massif occupies the NW. corner of France. It is composed chiefly of sericitic schists more or less metamorphic, of pre-Cambrian age, where synclines, some very narrow, composed of Paleozoic rocks occur. The prevalent tectonic direction, called the Armorican, is NW.–SE.

The Central Massif is situated in the heart of France. It is composed of crystalline or very metamorphosed schists, which are highly folded and are crossed by important masses of granite. The folds are of the Armorican direction in the west and of the Variscan direction, or SW.–NE., in the east. There are coal basins, chiefly at the periphery of the massif, the filling of which continued sometimes into the Permian. A recent volcanism (Pliocene and Quaternary) has principally affected the central zone of this massif.

The Vosges Massif, which is chiefly constituted by crystalline schists and by granite, was formerly connected with the massif of the Black Forest, in Germany. They were separated during the Tertiary by the formation of the Rhine graben. The Vosges Massif is now cut off towards the east by an important zone of faults, and plunges regularly to the north, east, and south, under the Triassic cover.

The Ardennes Massif, of which only the south edge occurs in France, is formed by Paleozoic folded formations, which are not metamorphosed. It continues under the Cretaceous plains of northern France as far as the Boulonnais anticline. The Franco-Belgian coal basin occupies a synclinal position in the interior of the massif.

THE ALPINE CHAINS

The Alps have a bow shape in the SE. corner of France. They consist of a series of overthrust sheets with complex tectonic forms. They are subdivided into a certain number of zones parallel to the axis of the chain. The interior zone has been affected by the metamorphism.

The Jura also describes a bow in front of the Alpine bow, which it replaces towards the north-west. The chain is essentially composed of Jurassic and Cretaceous formations folded in two groups, divided by a zone of plateaux. There is a décollement (separation resulting in extensive slippage) at the level of the Upper Triassic, and the front of the Jura is thrust over its foreland.

The Pyrenees constitute a more ancient chain than those mentioned above, and they are, therefore, more eroded. These mountains have approximately an E.–W. direction, and they include an axial zone of Paleozoic rocks, the southern side of which is Spain. Farther towards the north, the folding, which progressively decreases, affects a thick series, principally of Cretaceous age.

The Chains of Provence. These chains, which border the Mediterranean Sea, are related, by their structure and history, to both the Alps and the Pyrenees.

THE BASINS

The Paris Basin, with its 70,000 sq. miles, covers nearly one-third of France, and is the biggest sedimentary French basin. Its shape is classic and regular, and its filling, which only exceptionally exceeds 10,000 ft in thickness, dates chiefly from the Mesozoic and the Tertiary. The formations form a series of concentric halves, extending outward from the centre to the eastern border, and the oldest are situated at the periphery. On the other hand, in the west and north some formations transgressively overlap the older, the Upper Cretaceous particularly. In addition, the asymmetrical character of the basin is increased by the large development of the Triassic in the east and by its absence in the west.

It appears that the folding and faulting which break the uniformity of the basin are the result of the Alpine orogeny and correspond to late movements along Hercynian faults, the direction of which they adopt. Consequently, their direction follows an Armorican (NW.–SE.) trend in the western part of the basin, where the most important structure is found—the anticlinal of the Pays de Bray, which is the largest anticline in France. To the east of the basin, the tectonic directions have a Variscan orientation (SW.–NE.), and this region is influenced by the prolongation of the Hercynian anticline "Sarre-Lorraine." Finally, the southern part of the basin is affected by meridian faults, which are connected with the gravity faults of the Central Massif.

The Aquitaine Basin covers nearly 35,000 sq. miles in the south-west of France. It is limited on the north and east by Hercynian massifs in which since the beginning of Mesozoic time tectonic movements have been confined to repetition along Hercynian faults.

At its southern border, and here lies the main difference, the Aquitaine basin is bordered by the Pyrenean chain of mountains, which have affected both the sedimentation and structure in the basin.

The structural influence was strongest in the formations in front of the chain and diminished progressively towards the north.

From the stratigraphic point of view, it is necessary to note that the Triassic is an evaporate series in a great part of the basin, where it is the cause of a diapiric type of folding. Also to be noted with the first phase of Pyrenean tectonic is the transgressive overlap of the Upper Cretaceous.

The Rhone Basin and its Branches form a heterogenous whole, situated between the Alps and the Central Massif. It covers nearly 12,000 sq. miles, and comprises the following units:

The Bresse is located between the Jura, the Vosges, and the Central Massif.

The Savoie Basin has been a region of subsidence since the Oligocene period. It can be qualified as an intra-Alpine basin. It is uneven through the prolongation of certain folds of the Jura and of those of the sub-Alpine chains.

The Valence Basin has some analogies with the Bresse, but it has a more frontal position towards the Alps. The sub-Alpine folds vanish close to it.

The Camargue is a small Tertiary basin, with deep Oligocene troughs.

The Languedoc, situated between the Central Massif and the sea, is different from the above-mentioned regions, by its paleogeographic history, and by its complex structure. Numerous and complicated anticlines exist there, chiefly of the Pyrenean age.

The Tertiary Grabens formed in the middle of the Hercynian rigid masses, by the counter-stroke of Alpine folding, comprise chiefly the Alsace or Rhine graben formed between the Vosges and the Black Forest, which covers 2500 sq. miles, and the Limagne, the area of which is more reduced, and which is situated inside the Central Massif. The stratigraphic section is more complete in the Alsace than in the Limagne grabens. These two basins are highly faulted, the second of which is characterized by important and recent vulcanism.

RESULTS OBTAINED DURING THE YEARS 1954–55

Aquitaine Basin (Fig 4)

The Parentis discovery, in the Spring of 1954, has confirmed the early classification of the Aquitaine basin, in which for fifteen years the efforts of French exploration have been centred, as being the most important. Moreover, the position of the new field brought the interest back to a zone of that basin which had been somewhat neglected till then. In order to understand the consequences of this discovery it is necessary to place it again in its historical setting.

Brief History of Exploration Before 1954

That region, which in 1938 was designated to be explored, is situated immediately to the north of the Pyrenees. In fact, there were already known oil evidences, structures, particularly the anticlines of the Petites Pyrenees, where the St Marcet wildcat was located, as well as a thick sedimentary section of flysch type, resting unconformably with interposition of detrital layers, upon formations of various ages. On the contrary, more towards the north, there was a zone of few outcrops or no outcrops at all, practically without oil indications and where only some folds emerged, more or less well marked. Therefore, it was natural not to abandon this zone, but to give its exploration a secondary urgency, in order to proceed from the known to the unknown.

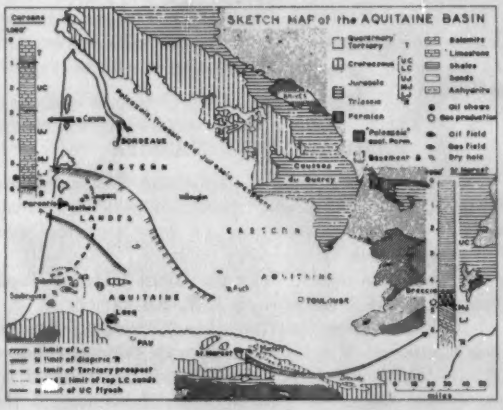

Fig 4

The St Marcet discovery, which confirmed the initial choice, has had as a counter-effect, and determined by hind-sight only, an adverse influence. It resulted in the greatest part of the exploration activity being concentrated in the zone initially chosen, the importance of which had been proved. Indeed, some successful results were obtained, such as the discovery of the Lacq field. But this activity was carried out in a manner which was prejudicial to other parts of the basin.

Moreover, it must be added that the different tentative operations started in these regions, and in particular in the central zone, did not furnish any very encouraging results. Technical difficulties, practically insurmountable, were met with at that time, which slackened the first seismic prospecting in the Landes. The stratigraphic section, on the other hand, was more reduced than in front of the Pyrenees, mainly limy, poor in cap rocks, and frequently flushed by fresh water.

It is easy to understand that in these conditions the Parentis discovery, situated in the west central part of the basin, has had a great and lasting influence and has brought about a new distribution of the exploration effort throughout the whole basin.

The Parentis Field (Fig 5)

Several publications are devoted to the Parentis field.[1,2] It will only be recalled in this paper that the discovery of the structure must be attributed to the credit of the seismic reflexion method, oriented by a preliminary gravimetric survey, which initially had to overcome great technical difficulties connected with the surface conditions, as has been already mentioned.

The Parentis anticline is about 6 miles long and 2·5 miles broad. Its section is asymmetrical, and its southern side is abrupt and probably faulted.

On the top of the structure, the reservoir is reached towards 6500 ft, under 4700 ft of Tertiary, and 1800 ft of Cretaceous, and the oil column attains 1350 ft. The reservoir is of Lower Cretaceous to Upper Jurassic age. It is a limestone, partially but irregularly dolo-

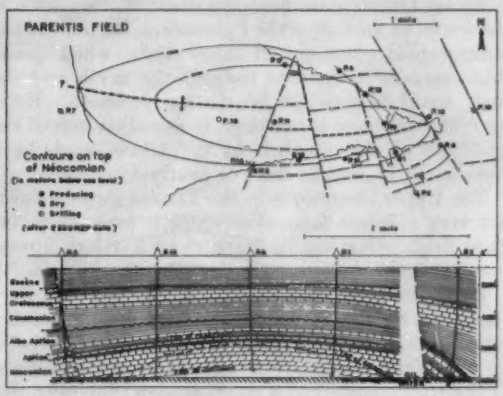

FIG 5

mitized, the dolomitization being more developed in the zone of culmination of the structure.

Parentis is the largest French oilfield. Towards the end of 1955, fourteen wells had been drilled on the structure and two other wells were drilling. The production is obtained from eleven wells, two of which are pumping, spread over a producing area of 6000 acres. The cumulative production to the end of the year totalled 5,170,000 brl, and the daily rate at that time was approx 17,000 brl. The oil is 33° API, contains very little sulphur, and has a gas–oil ratio of only 75 cu. ft/brl. The productivity of the wells in Parentis varies with the porosity and extent of dolomitization, ranging from less than 1 brl/lb drop in bottom hole pressure to as much as 1675 brl/lb.

Exploration in Western Aquitaine: Lower Cretaceous Prospect

It is necessary to note that the Lower Cretaceous (Neocomian), which composes the greatest part of the Parentis reservoir, does not outcrop at the NE. border of the basin, where the Upper Cretaceous overlaps the Upper Jurassic. It was generally considered that in the southern part of the basin the Neocomian was missing, the Upper Cretaceous resting disconformably upon Middle Jurassic or older formations.

The search for fields of the Parentis type, postulated in the first place a definition of zones where the Neocomian was present. The stratigraphic and paleogeographic studies, which were immediately started, gave important results, at the start permitting the recognition of Neocomian and Upper Jurassic in a great number of previously drilled wells.

It appeared, in particular, that the reservoir of the Lacq gas pool was of Neocomian age, as well as different formations which had given very important oil shows in previous wells. Thus, the oil prospects of the Neocomian were emphasized. Besides a first project of the Neocomian "basin," the region of the Landes began to be outlined. Thus, since the middle of 1954, the Landes have known an increased activity.

As the absence of outcrops was almost complete, it meant, first, seismic prospecting and, then, drilling.

At the beginning it was known that the chief difficulty of the exploration would come in the greatest part of this region from the presence of a diapiric saliferous Triassic, which seemed to play an increasing role from north to south, where it reached the surface in many places. It was planned to examine first the structures less affected by the diapirism, in order to test the Neocomian in a high position. The exploration of the flanks of the diapiric structures has been postponed, on account of the difficulties presented by such exploration.

From the middle of 1954 to the end of 1955 nearly fifteen wildcats were drilled in the Landes. In the first place, they showed that the diapiric manifestations of the Triassic, in the north, do not extend beyond a zone situated somewhat to the south of Parentis. They also confirmed a fact known through the former wildcats, that on the top of the diapiric structures the stratigraphic section is generally incomplete. The interpretation of these gaps is more difficult than might appear *a priori*. In fact, a formation can be absent for different reasons, which can, moreover, be simultaneously:

(*a*) Tectonic suppression, and in the present case existence of faults, connected with the diapiric intrusion.

(*b*) Stratigraphic gap, which can be local, limited to the area influenced during the sedimentation by the rising of the diapir, or regional, if the Triassic merely deformed a series already incomplete. This last possibility could lead one to doubt locally the reality of the diapirism, and to suppose the existence of shoals constituted by the Triassic with a transgressive onlap of the more recent formations.

(*c*) Erosion, also connected with the diapiric rising.

In addition, the stratigraphy of the Mesozoic, in Aquitaine, is very difficult to determine, and reliable key horizons there are very scarce, so that the interpretation, and particularly the paleogeographic one, of the results obtained presents considerable difficulties. The seismic profiles are not sufficient for the

joining of the different areas worked, and only the drilling of the flanks of structures permits a choice to be made between the different hypotheses, the practical consequences of which are very important (existence or non-existence of the Neocomian along the flanks of the diapiric structure; the kind of limits of the Neocomian "basin"; deposition or erosion; and so on).

To sum up the problem, a comparison may be made between the Aquitaine and the NW. basin of Germany. It is known that simple theories concerning the origin, the migration, and the accumulation of the oil in this basin have been elaborated in the past few years. But it is only possible to speculate on what would become of the geological conceptions regarding that region if the wells had been located solely on the top of the salt domes.

Whatever it may be, the wildcats of the past two years on the diapiric structures of the Landes have not yielded any important oil show.

The Mothes Field

Ten miles to the east of Parentis, in a zone which seems to be free from diapirism, a new field was discovered in May 1955, on the Mothes structure, a faulted anticline, separated from Parentis by a saddle which is also complicated by faults. The discovery well, at a depth of about 8000 ft, is producing about 350 b.d., from a formation which is equivalent to the reservoir of Parentis. The oil is somewhat heavier, 21° API against 33° API. The water table is not yet well determined, but it seems to be situated definitely lower than in Parentis. It is interesting to note that there was no oil show on the producing horizon during drilling. The casing was perforated on the basis of the indications supplied by electrical and radioactive logs.

The possibilities of the Neocomian will probably be better defined during 1956 after wildcats have been drilled in the Landes. These wells, and particularly those which will be located on the flanks of the diapiric structures, will lead to a better understanding of the Neocomian basin. Moreover, the exploration of the northern part, of this "basin," the prospective portions of which have been fairly well outlined by wells drilled and seismic work, will be soon started, and it is hoped that stratigraphic traps will be discovered here.

Other Prospects of Western Aquitaine

Though the Neocomian constitutes the major aim in the Landes, other levels present prospects which are not being neglected by the explorers.

The transition zone between Jurassic and Triassic contains dolomitic horizons, which have supplied good shows of heavy oil, in two wildcats located in the north and in the east of the Landes (Bouglon and Carcans) in a zone where the Upper Cretaceous lies directly on the Jurassic.

The Jurassic itself, chiefly the middle Jurassic, to the exclusion of the uppermost Jurassic—at Parentis this composes the lower part of the producing formation—contains different reservoirs, which have supplied oil shows, so far of little importance. These formations have not yet been explored on the Parentis structure.

A wildcat (Saugnacq), located some kilometres towards the east of Mothes, has met reef limestone of Aptian age nearly 1500 ft thick, which is included in the shales series forming the cap rock of the Parentis field. It seems that it must be a bioherm, constituting an ideal reservoir, and although without oil shows in that wildcat, could become an interesting aim for exploration.

The Albian stage is generally to be found in a tight facies. However, two wildcats drilled in the southern part of the Landes (Saubrigues and Sebastopol) encountered at this level important thicknesses of sands having variable porosity and permeability. These facies are known in the outcrops situated more towards the south, at the foot of the Pyrenees. The zone of the stratigraphic pinch-out of these sands, which grade into compact formations towards the north and the east, could become an interesting prospect. However, this problem is not easy, in consideration of the questions of the cap rock, as the Albian sands have been found to contain fresh or nearly fresh water.

The Upper Cretaceous in the Landes shows a facies not very different from that which it presents in the Lacq field. Overlain by impervious Tertiary formations, it could therefore offer interesting prospects.

Finally, recent wildcats have shown that the Tertiary "basin" of the Landes deepens considerably towards the west, and this fact is made more valuable by the existence of good reservoirs, salt water bearing in the Oligocene. Traps could be determined in this series either by faults or by stratigraphic changes connected with the variation in thickness.

Conclusion on Western Aquitaine

The above enumeration shows why the Landes is today the most important centre of exploration activity in Metropolitan France. The following data show the importance of the operations towards the end of 1955:

Nine seismic parties.
One telluric party.
Six rigs for deep exploration.
Three rigs for shallow exploration.

Exploration in SW. Aquitaine

This concentration, however strong it may be, is not exclusive, and it has not stopped the exploration of the Lacq gas pool in SW. Aquitaine.

The Lacq Gas Pool (Fig 6)

This pool was discovered in 1951, by a deeper pool test, Lacq No. 3. At a depth of 11,700 ft a prolonged and violent blow-out occurred when the top of the gas reservoir was reached. In fact, the characteristics of

the gas pool subsequently measured are rather exceptional.

Bottom pressure, 9200 p.s.i.
Bottom temperature, 248° F.
Hydrogen sulphide, 15 per cent.
Carbon dioxide, 9 per cent.

The whole of these conditions and the great depth have retarded development of the pool. Since 1952, two heavy-duty rigs have been in service. The production tests met with great difficulties, as the gas was highly corrosive, so that longer tests became possible only in 1956, after a special and very resistant steel had been developed.

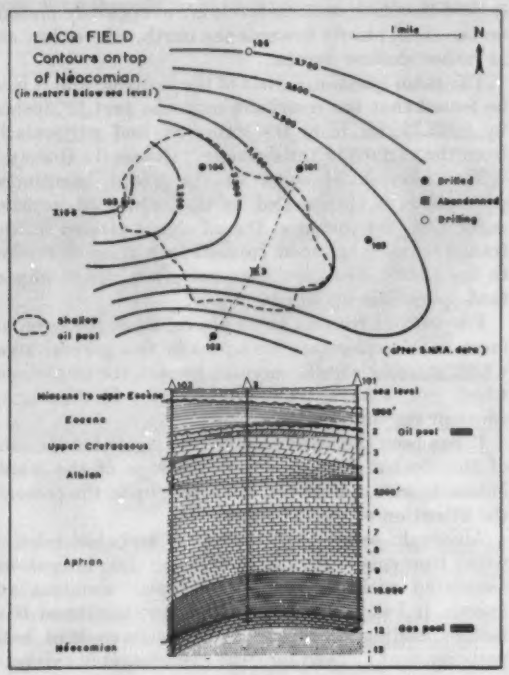

FIG 6

Today, four wells, besides Lacq No. 3, which had to be cemented and abandoned, have been completed, and two others are drilling inside the gas reservoir. Their spacing is between 1 and 1·5 miles. All the wells drilled found gas. None has found the water table, although the deepest went to 14,275 ft,* 3000 ft in the reservoir. However, this figure should not be misinterpreted, as the facies of the reservoir and its physical characteristics are extremely variable, and only 750 ft of the total thickness shows an average porosity over 2 per cent.

The structure of the gas pool is not yet well known. The seismic picture is not very good, notwithstanding the efforts made, probably as a result of the depth and the high proportion of limestone in the stratigraphic section. The broad and regular seismic dome has been partly disproved by the well data. But this fact has still some favourable influence, as the dimensions of the structure are larger. The most westerly well, Lacq No. 105, which was still drilling at the end of the year, is also structurally the highest: it has reached the top of the reservoir, towards 10,500 ft. The shallow structure known through the exploitation wells of the oil pool, about 2100 ft deep, is not conformable with the deep structure.

The reservoir is of Neocomian to Upper Jurassic age, as that of Parentis, but less dolomitized, and consequently has very many fewer favourable characteristics.

It is yet too early to determine the amount of the reserves of this gas pool, which are, in any case, very large, and the value of which is reinforced by the production of sulphur, which can be obtained.

Recently, during the development of this pool, an interesting result has been obtained, not for its immediate consequences, but for the possibilities which it opens. Very important oil shows have been gathered at Lacq No. 105 from a detritic layer interbedded with the shales of the cap rock, about 300 ft above the reservoir.

Though the production tests did not give any economic result, by reason of the poor quality of the reservoir, the fact that these indications have been obtained in the highest well to date suggests that an improvement is possible towards the west in connexion with an eventual rise of the structure in this direction.

Exploration in the Southern Neighbourhood of the Landes

Before leaving the western part of the Aquitaine basin, it is necessary to note the tendency which is now apparent in the zone adjacent to the sector of Landes towards the south. This zone has been for the past eighteen months more or less neglected because of activities carried out in the north.

However, various oil shows have been already encountered there, particularly in the Neocomian. But the development of the exploration from these indications appeared to be difficult in view of the diapiric nature of the structures, and it has been delayed.

Difficulties of the same kind have also been brought out by the recent wildcats in the Landes.

Thus, there is no main difference between the two areas, and it is the reason for the present return to the southern zone.

Exploration in Eastern Aquitaine: General Tendency

When considering Eastern Aquitaine, it is necessary to stress the fact that its geographical and geological situation does not permit it to benefit directly from the Parentis discovery, as has been the case for the Landes. In fact, in spite of the stratigraphic modifications mentioned above, it is quite certain that the Lower Cretaceous and the Upper Jurassic are not present over

* Lacq No. 104 is the deepest well drilled in Western Europe.

the greater part of this region. The reason for this absence can be either a gap in the sedimentation upon the structurally high areas, and near the borders of the basin of deposition, or an erosion consecutive with the Pyrenean tectonic phases.

If the tendency shown in this region was rather in the way of a reduced activity, it will be readily understood that the two past years have not yielded a development comparable to that which took place in the Landes.

The above mentioned tendency is the consequence of the fact that in spite of important efforts, the gas field of St Marcet has remained the only discovery in the area.

Attempts were made to explain this fact, suggesting that this mushroom shape diapir fold, which becomes a simple anticline above the Upper Cretaceous unconformity, has been deeply truncated by this unconformity. Therefore, it appears to be a buried structure, which could have acted as an early trap. At a later period, after the deposition of the present cap rock of Upper Cretaceous flysch, the structure formed before the Upper Cretaceous took its present complex shape. It permitted the migration of the previously trapped hydrocarbons into the breccia resting unconformably on the buried anticline and capped by the flysch. Now it seems that all the structures which appear to be similar to that of St Marcet that have been explored to date are in reality different, because they did not form before the Upper Cretaceous. Exploration work under these conditions is obviously very hazardous, and especially so if to the other difficulties are added complicated paleogeological conditions, inherent in diapiric structures, hidden under a thick cover of flysch.

Exploration in Eastern Aquitaine: Prospects and Operations

A well is now being drilled six miles east of the St Marcet field along the same trend where two wells were drilled previously but which did not reach the pre-Upper Cretaceous core.

In the same direction, but sixty miles more to the east, a fifth well will probably be drilled in order to explore the large Dreuilhe anticline, which is different from that of St Marcet by the fact that the flysch lies directly upon a pre-Mesozoic substratum. Yet, the favourable factors are partly offset by the irregular distribution of porous beds in the flysch. These beds have given good gas shows, but because of their unfavourable characteristics they have not furnished any production.

The problems outlined, the difficulties of which are obvious, are nevertheless not the only ones to be overcome in that part of Aquitaine.

To the north of the trend of St Marcet, the Upper Cretaceous flysch grades into the limestone facies of the shelf area which bordered the flysch trough on the north. The transition zone presents a favourable balance between the reservoirs and the cap rocks, and the Lacq oil pool is located in that zone, more towards the west. Consequently, there exists an objective for exploration, but a difficulty comes from the fact that previous wildcats have shown that it could be, at least locally, extremely narrow.

More towards the north, the Upper Cretaceous is irregularly present and generally not well capped. But in the lowest parts, which are the best protected from erosion, it is hoped to find again the Neocomian and the Upper Jurassic. Such an occurrence is, however, hazardous, as has been shown by a wildcat (Auch) located for this purpose, which did not find these formations.

The prospecting of the Liassic, which contains dolomitic limestones, and the Triassic, with its dolomitic and sandy reservoirs, does not encounter the same difficulties, as these levels are everywhere present on the shelf, chiefly towards the north, where they are at rather shallow depths.

The main question is that of the capping, and it is to be feared that the reservoirs might in part be flushed by fresh water from the outcrops, and particularly from the surface in the Jurassic "Causse du Quercy."

The interest of some of the above mentioned possibilities is emphasized by data obtained in other regions, as, for instance, the oil shows yielded by the transition zone between Jurassic and Triassic, farther to the west. But they have not given rise to important operations up to now.

For various reasons given above, there has been an increase in exploration activities in this general area, which increase should serve to correct the impression which might have been received of a slackening of effort in the southern zone.

It has been the same case for the whole border zone of the Central Massif, where outcrops of the whole Mesozoic section have not attracted, up to the present, the attention of the explorers.

Although several structures in probable relation with Hercynian faults, and some oil indications associated with different stratigraphic members are known, it has, for a long time, been considered that factors leading to migration losses have here been preponderant. Therefore, the exploration in this zone has been started only recently, and no wildcat has yet been drilled.

The objectives here are only Jurassic, Triassic, or Paleozoic. The former two show themselves under the same conditions which have been mentioned above, with two exceptions: a lesser depth and a possibility of a favourable evolution of the reservoirs in the direction of the NE. margin of the basin. As for the Paleozoic prospects they chiefly concern the Permian formations, and their value is increased by the bituminous facies, known in the little basin of Brives situated on the border of this marginal zone, as well as in other places in France where bituminous shales are worked. It is evident that in this zone, having a thinner Mesozoic section, the exploration of these formations, filling limited basins inside of Hercynian massifs, is easier than in deeper parts of the basin.

The Paris Basin (Fig 7)

Although the Paris basin is the largest of all the sedimentary basins of France, its exploration began only some years ago.

Unfavourable Factors

What are the reasons which had, up to that time, discouraged the explorers?

In the first place, in spite of the drilling of thousands of shallow wells for water supply and ore prospecting, and in spite of a very good knowledge of the field geology, practically no oil shows had been found there.

On the other hand, the generally neritic or littoral facies, coupled with their apparently reduced thickness, were thought to be unfavourable to the genesis of

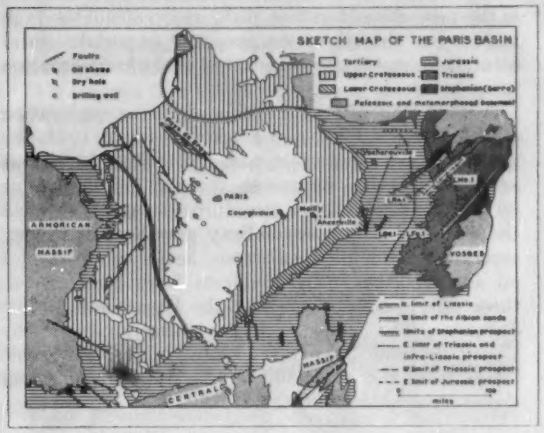

Fig 7

hydrocarbons. Finally, the structural characters of the basin, poor in anticlines, also discouraged the explorers.

Nevertheless, if the structures are not numerous, the Pays de Bray anticline, over 60 miles in length, is, as mentioned above, the largest anticline of France. Unfortunately, the first wildcat, drilled in the years 1924–27 down to the basement, was a failure. It is true that it was located 2·5 miles from the anticlinal axis.

Favourable Factors

In 1950 the National Administration wanted to evaluate the oil possibilities of the basin, in order to induce an interest on the part of explorers.

It was considered that the above mentioned arguments were not sufficient to prove the total absence of interest, and they could be counterbalanced by some more favourable considerations.

The Paris basin communicated widely, during the Jurassic times, with the German basin, where the Jurassic is productive. In Alsace, which is situated in the communication zone between the basins, some small oil pools have been found in the Triassic and Jurassic, which show facies and thicknesses very similar to those of the eastern part of the Paris basin.

The main part of the basin is covered by Tertiary and Upper Cretaceous formations which are, however, without interest for oil exploration. Up to 1950 no deep well had been drilled, and as the geophysical data remained very meagre, the structural and stratigraphic conceptions concerning the deep zones of the basin remained hypothetical.

Exploration in the Eastern Part of the Basin

The preliminary work conducted by the National Administration was successful, inasmuch as at the end of 1952 two companies showed an interest for the eastern part of the Paris basin, the favourable possibilities of which had been particularly stressed.

Three prospective areas seemed to justify prospecting efforts.

(1) The first was in relation with the Stephanian (Upper Carboniferous) formations and mainly located at the prolongation in subsurface of the Sarro-Lorraine anticline. The interest in these formations was determined by their regional tectonics, responsible for the existence of well-defined anticlines and chiefly by the important seepages, known in the coal mines of the Sarre. Stephanian exploration was rather deep.

(2) A Triassic and lower-Liassic (Rhetian) prospective area in part, superposed on the preceding one. These formations contain different reservoirs, particularly the lower-Liassic sands, and they are affected in Lorraine by deformations. Thus were formed different structural traps which are small but easy to locate by field geology and by core drilling.

(3) A Jurassic prospect, which concerns the most westerly part of this zone, and which is determined by the existence of sandy reservoirs in the Liassic, outcropping on the north-east margin of the basin, and limy reservoirs, in the Middle Jurassic. The structural aspect of this exploration is a matter of geophysics.

These different prospects have been approached by drilling after geological and geophysical preparation since 1953, and the results obtained furnish a preliminary answer.

The Stephanian has been explored by two wildcats, one of which (LRo 1) was located on the south-west prolongation of the Sarro-Lorraine anticline, and the other (LMo 1) upon a satellite structure of the main axis. Though some oil shows have been found, the poor qualities of the reservoirs have been rather discouraging. A third wildcat (LGe 1) located in a more westerly situation for mesozoic exploration will be deepened into the Paleozoic.

The Triassic, drilled through by ten wells, which permitted determining the extension towards the west of its marine facies, has shown some oil shows, only quite recently, in a shallow test (LFo 1). Its exploration will be pursued near the zone of its outcrops,

where it can be easily reached by drilling, and where locations can be determined at moderate cost.

The results obtained in the lower-Liassic are more encouraging. This formation has shown oil impregnation in two different wildcats (Courgivaux and Mailly) situated 35 miles from each other, the locations for which were fixed in accordance with seismic data, which were rather poor.

Unfortunately, the low porosity and permeability of the reservoir did not permit commercial production. However, a porous and permeable facies of the lower-Liassic was encountered in two other wells more towards the east (Ancerville and Vacherauville), but no oil shows were found.

The exploration of the Jurassic has, at first, looked for the verification of the possible existence of a Liassic trough in the NE. part of the basin.

This verification was important not only for the Liassic itself—but also for the analogy with NW. Germany, where the location of the oilfields seems to be closely connected with the occurrence of Jurassic troughs.

Unfortunately, the above hypothesis was not confirmed by a first wildcat (Vacherauville), and the exploration was continued by three other wells scattered over the area prospected.

Important impregnations have been found in the Middle Jurassic in the two wildcats which have been mentioned above for their lower-Liassic oil shows (Courgivaux and Mailly), but, as for the lower-Liassic formations, the tests did not yield any commercial production. However, for one of these wells, a second series of tests is envisaged.

Exploration in the Western Part of the Basin

It is interesting to compare these results with those obtained in the western zone of the basin. This zone indeed had soon attracted the interest of the explorers, and the first wildcats were drilled towards the middle of 1954.

Exploration of the Pays de Bray Anticline

It was logical that the large anticline of the Pays de Bray be explored first.

A wildcat located in a high position, according to the surface data, reached the basement towards 3500 ft deep, after having shown oil traces in the top of the Middle Jurassic, towards a depth of 1600 ft. This formation was then acidized and swabbed. Up to 150 b.d. of anhydrous oil were produced initially, then water appeared in rapidly increasing proportion. After installing a pump on the well, the gross production rate settled to about 60 b.d., of which 6 brl was heavy oil (24° API), with a high viscosity and without gas. The efforts made in 1954 and 1955, in view of developing the pool, have been disappointing. In fact, notwithstanding a sometimes better structural position, more abundant oil shows, and in spite of the application of different techniques of completion and production, none of the seven holes drilled around the discovery well gave a production better or at least equal to that of this first well. In the last instance an hydrodynamic hypothesis was postulated in an attempt to account for this peculiar phenomenon. But the search for an accumulation which could have been shifted with respect to the top of the structure, and which the discovery well would have reached on its border, remained unsuccessful. The exploration of a secondary top of the anticline of the Pays de Bray, fifteen miles north-west of the main one, remained also without results. Somewhat lower on the surface than the main high, its structural position at depth could have been found to be relatively higher as a result of an appreciable reduction in thickness of the Upper Jurassic.

Nevertheless, in conclusion, it can be stated that a small oil pool exists on the structure of Pays de Bray, but oil cannot be economically produced on account of the poor characteristics of the reservoir, of the high viscosity of the oil, of the generally important water saturation, and finally on account of the low formation temperature.

A short time after the beginning of the exploration of the Pays de Bray and from the end of 1954, the prospection of the western part of the Paris basin was extended to other structures, more or less detectable by field geology. These structures, being deeper than the structure of the Pays de Bray, gave hope of finding, especially in the middle Jurassic, better conditions for oil accumulation. Five wildcats have been drilled, three of which explored only the Upper and Middle Jurassic. The latter and also some levels of the Upper Jurassic have been found under favourable facies from the viewpoint of reservoirs, but no oil shows have been found there.

Present Tendency and Conclusion on the Basin

These results, nevertheless, in no way discouraged the explorers. These are specially interested in the region north-east of Paris, which is the object of a strong competition. This zone seems to be, in fact, particularly attractive due to its intermediary position between the Pays de Bray with its heavy oil shows and the deepest part of the basin, *i.e.* on a possible path of migration. In the most eastern part of the basin, where is located the Stephanian prospect, already mentioned, are presently studied the possibilities, still highly theoretical, of the older Paleozoic formations, the lower Carboniferous, and the Devonian.

It must be recognized, however, that the exploration of the Paris basin is difficult.

On the one hand, there is, as yet, no good lead for the delimitation of the favourable zones as reservoirs are concerned, especially when these reservoirs are limestones. On the other hand, on the inside of such zones, traps have still to be found. Now the few structural traps are generally not very well defined. Consequently, their localization by geophysical methods, including seismic, presents problems yet incompletely solved.

As to the eventual stratigraphic traps, the uncon-

formities within the stratigraphic section are not of very great importance, and determine pinch-out only near the basin's margins, where the possibilities of capping are poor. The theoretical interest of the Albian sands has been reported, for they pinch-out in the direction of the Armorican Massif. These formations outcrop at the eastern margin of the basin and do not reappear towards the west. The situation has been compared to that which exists in East Texas : the up-dip edge of the Woodbine sands (Upper Cretaceous) arched by the folding of the Sabine uplift and forming the trap in which the largest pool in the Western Hemisphere accumulated. Unfortunately, the Albian sands are flushed by fresh water up to the centre of the Paris basin, and the map of the formation pressures suggests the probability of not being capped by impervious formations to the west.

Finally, it is not impossible that the oil entrapment in the Paris basin be also complicated by hydrodynamic conditions which are still hypothetical.

It is evident that the topography of the basin could not determine important pressure gradients. But on the other hand, their consequences could be important upon structures with poor closure and low dips, such as those of the Paris basin, where a slight tilt of the water table can determine an important shift of an oil pool.

The Rhone Basin and its Branches

As mentioned above, the Rhone basin differs from the Paris and Aquitaine basins in that it is divided into several and sometimes complex units.

These different units have been more or less actively explored, but the past two years have shown for some of them an important reduction of activity, as no discovery has been made.

This concerns in particular two adjacent regions, which had been explored with the main intensity, namely the Languedoc and the Camargue.

(1) *The Languedoc*

The Languedoc is geologically as heterogenous as the Rhone basin itself.

At the border of the Central Massif it is astride on different areas of sedimentation, and it has been affected by different tectonic stresses. The present geological conditions are therefore quite complicated, and this region would have appeared to the explorers of minor interest if some surface occurrences of petroleum had not been found in connexion with different stratigraphic members.

Therefore, it is not surprising that the starting point of the exploration had been one of these surface evidences, known of old, close to which had been discovered the little Gabian Triassic field mentioned above.

Subsequently, the exploration continued in two directions. First, other accumulations of the same kind were looked for in the zone of the basin border, but the tectonic complications met with were discouraging.

Secondly, efforts were made to localize in the deeper zones some traps on the probable paths of the migrations, which have fed the oil evidences of the border. The structures were numerous, but their exploration, in spite of occasional promising showings, remained disappointing, there being no reservoirs or very poor ones.

Consequently, at the beginning of 1952, the activity was considerably reduced.

However, the Languedoc was also, in part, favourably influenced by the important changes in the Upper Jurassic and Lower Cretaceous stratigraphic conceptions above mentioned with regard to the Aquitaine. The hope of finding a complete Jurassic section as well as dolomitic facies in a zone which was up to then considered to be lacking in those formations led to the drilling of a new wildcat. This well was located on one of the structures of the Western Languedoc not previously tested. It confirmed the initial stratigraphic hypothesis, but it did not encounter any valuable oil show.

Some exploration projects which remain to be carried out must solve in so far as possible old but untested areas; thus, a wildcat has been located in the zone where the impervious Jurassic grades from east to west into good but generally open dolomitic reservoirs.

Finally, one will understand that the present conditions of exploration in Languedoc are not too encouraging.

(2) *The Camargue*

The Camargue offers to the exploration quite different problems, inasmuch as they chiefly concern the Tertiary and particularly the Oligocene formations.

In fact, the Camargue, which corresponds essentially to the delta of the Rhone river, is entirely covered by Quaternary formations. It is for this reason that its interest for oil exploration was first suggested by a gravimetric survey which discovered a deep basin showing different uplifts and bordered towards the west by an important gravity fault.

The well data have confirmed the initial conception, and they have also revealed the large amount of Tertiary fill which exceeds locally 11,000 ft, of which 8000 ft is Oligocene. This thickness, and the possibility of mother-rocks inside the section, as well as the very valuable oil evidences found in a little Oligocene basin, situated 30 miles more to the north previously explored, were the reasons why the exploration in the Camargue was centred upon this Oligocene.

A success obtained in 1951 led to the location of some ten wells in the region of Gallician, where some oil has been produced from different horizons. Unfortunately, the slight thickness of the reservoirs, situated about 6000 ft deep, and their poor porosity and permeability did not permit a really economical production. The total production is only about 20,000 brl and, thus, the presence of a large oil pool is unlikely.

This result, added to the failure encountered in other

places of the Camargue, explains the very limited exploration activity of the past two years.

The main effort has been centred in the neighbourhood of Gallician. The deep Oligocene exploration, which remained to be made, has been drilled, without success, down to 12,000 ft. Moreover, it has been acknowledged that the extension of the Gallician facies was very limited towards the south, where it grades into rather tight formations without good shows.

At present, some activity is being displayed in the Camargue and in particular close to the north of Gallician, where a well after two years of production is still yielding 6 b.d.

This area remains practically undrilled, and the extent of the oil shows encountered at Gallician would justify some additional efforts.

(3) *The Savoie Basin*

Though the intra-Alpine situation of this basin makes it different from the Camargue, the two basins present a certain analogy in their Tertiary fills. In particular, the Oligocene outcrops in Savoie show different oil evidences which have made it the objective of the first prospecting work.

However, wildcats have not confirmed the hopes put in the Tertiary series. The qualities of the reservoirs were generally very poor. Upon the deepening of some wildcats oil shows were found in the Mesozoic formations, and exploration work was then aimed at these horizons. They were studied during 1953–54 by two wildcats located on an anticline on the western border of the basin, this anticline being a fold of the Jura; the two wells encountered some oil shows in the Middle Jurassic.

No well was drilled in 1955 in that region, but exploration will probably be resumed in the near future. In fact, it cannot be considered that the exploration has been finished after the limited work which has been conducted in this region. Moreover, no work was done in the northern part of the basin situated close to the Swiss frontier, which seems to draw the attention of some new explorers. Furthermore, this interest is increased by the new discoveries made in recent years in the German part of the Molassic basin.

(4) *The Bresse*

The exploration history of this Tertiary basin, which began only a few years ago, is somewhat similar to that of the Savoie basin. Here also, the exploration which aimed at Tertiary formations at first was soon directed towards the Mesozoic, as the Tertiary, especially the Oligocene facies, was not very encouraging, also some oil shows were encountered in the Middle Jurassic and in the Triassic.

In the course of the past two years two wildcats tried to evaluate these indications on a faulted structural uplift on the western border of the basin, but without success.

The exploration is now migrating more to the north. An early uplift is there present, and it has been apparently better preserved from migration losses than the structures of the basin border. Furthermore, different wedge-outs, discovered by seismic survey, give an added attraction to this region.

(5) *Other Regions*

The Valence basin, situated half-way from the Camargue and from the Bresse, has recently attracted explorers on account of the preliminary work conducted by the BRP. Two surface structures have been detected and geophysical surveys have been undertaken, but no wildcat has yet been drilled in the basin.

The prospects, there, concern three different formations:

(*a*) The Oligocene, which seems likely to exceed 6000 ft in the centre of the basin. There are known reservoirs, cap rocks, and very slight evidences of oil. The Oligocene problem is similar to those of Camargue and Savoie.

(*b*) The Upper Jurassic, where dolomitic and reef facies are known in the sub-Alpine folds, which border the basin towards the east.

(*c*) The older Mesozoic horizons. Their interest still remains theoretical.

It must be noted that the position of the Valence basin, in front of the Alpine bow, is very attractive, and that this situation compensates in part the disadvantages resulting from the small area of the basin. Also many things remain unknown regarding the evolution of the Mesozoic facies in front of the Alpine chains, transverse to the basin. There may be agreeable surprises, especially in the Cretaceous formations.

For the sake of clarity, it seems advisable to describe with the Rhone basin different sedimentary regions which are close to it or which offer prospects of the same kind to oil explorers.

The Jura, a folded chain, with many anticlines, which are often of simple shape in the shallow formations but become complicated in the deep ones, separates the Bresse from the Savoie basin.

The exploration of the Jura began on account of the chance discovery of small Triassic gas pools in two places along the border, 60 miles apart from each other. Two difficulties were obvious as far as exploration was concerned: the poor and changing quality of the reservoirs and the complex tectonic conditions of the border zone, on account of the *décollement* below the Upper Triassic, *i.e.* above the reservoirs. But these reservoirs could be reached by shallow wells and geophysical prospecting was not necessary.

A dozen wildcats located chiefly close to the most northern of the two small gas pools and the same number of wells drilled in the same sector, for coal prospecting, did not give any result. They confirmed the unfavourable character of the reservoirs and revealed tectonic conditions even more complicated than supposed—the Jurassic border overthrusting the Bresse basin. So towards the end of 1952 the exploration of this zone was stopped.

The year 1955 saw the starting of renewed activity owing to an oil and gas show which was found in a core-hole drilled for coal in the same sector. This well presented the interest of being situated in a more internal zone than the previous ones where the structure is more simple. Unfortunately, some wells drilled to evaluate the extension of the pool remained without results, and the exploration has once more been stopped.

In the course of 1956 some shallow wells will be drilled, close to the most southern gas pool, which occurs within the overthrust formations rather than below, a factor which permits an efficient use of the indications of the surface geology.

Up to the present, the Jura has not been prospected outside its west border. The reason is that the majority of the geologists think that in the whole chain there exists a general *décollement* at the base of the saliferous clays of the Upper Triassic, which renders the prospecting of the underlying reservoirs of the Middle Triassic very difficult. As to the other objectives, they seem to be limited to the Middle Jurassic, which is generally not or imperfectly capped. Also, important questions of pressure, and of fluid circulation, are to be examined on account of the topography of this chain.

Yet some interest is now shown in that relatively virgin region. In particular, it seems that more favourable tectonic conditions exist at the junction of the folded chain with its foreland, towards the north-west and perhaps also in the zone of plateaux, which occupies the centre of the chain and where the *décollement* of the Upper Triassic is not certain.

The Provence can be brought together with the Rhone basin for its geographical position.

Geologically, it is related to the Pyrenees, with which it seems to be connected under the Mediterranean Sea. Like the Pyrenees, it has to the south-east crystalline and Paleozoic massifs. North of these massifs, the Mesozoic is folded in an east–west direction. Also, the formation of different basins has been determined by the major phases of the Pyrenean orogeny during middle Eocene time. In these basins, the thickness of the Oligocene and the more recent formations can be large.

Between these basins, the Digne basin recently attracted the attention of the explorers by its rather large dimensions and by the existence at its western border of many oil occurrences in the Oligocene. Hence, the exploration was aimed at the Oligocene and directed towards the surface structures. The facies of the Cretaceous appeared also to have some interest.

The only wildcat drilled up to the present in the basin was during the first months of 1955, and this gave unforeseen results. Both Oligocene and Cretaceous were absent, and the Miocene lay directly upon the Upper Jurassic at 6000 ft. This opened a new prospect: the exploration of the dolomitic reservoirs of the Middle Jurassic considered favourable because of surface oil occurrences and shallower than previously estimated.

The exploration of the big Cretaceous anticline east of the Rhone valley is still to be done, and two applications for exploration permits have been recently made for this purpose.

The Small Roussillon Basin, which lies on the east-plunging end of the Pyrenees, is related hypothetically with the Rhone basin, assuming, as is the case for the Camargue, it is only a branch of a larger basin, submerged under the Mediterranean Sea. After the results obtained in the Camargue, it was logical to explore there the Oligocene. The proximity of the Pyrenean chain, which is a source of detrital material, could have had a favourable influence on the evolution of the reservoirs. One wildcat only has been drilled, in 1954, upon a geophysical structure of the basin, and, as happened in the Digne basin, its results have been quite unforeseen. In fact, the Oligocene is almost entirely missing. The Tertiary consequently loses a great part of its interest. At the same time, other problems may be encountered in the north of the basin, in the eastern prolongation of the zone which has been prospected in Aquitaine, in front of the Pyrenees.

The Tertiary Grabens

Alsace is the only Tertiary graben which is now prospected.

(1) *Limagne Graben*

In fact, though different oil evidences have been known there for a long time, the Limagne was the object of only a modest and scattered exploration activity, rather a long time ago.

In 1953 the National Administration wanted to evaluate its oil possibilities. The results of the geological and geophysical studies have not been encouraging.

> The oil occurrences are generally found in the form of viscous and sulphurous bitumens.
>
> The reservoirs are few and irregularly distributed.
>
> No structure having a well-defined closure has been found.
>
> Strong volcanic influences are known in the southern part of the basin.

(2) *Alsace or Rhine Graben*

Alsace presents itself as the oldest French oil province, and its possibilities are far from being exhausted, in spite of the small area of the basin. In comparison with the Limagne this basin is characterized by marine influences more accentuated during the Oligocene, and which is still more important in regard to oil exploration, in view of the fact that the Tertiary did not lie directly upon the metamorphic or, sometimes, Paleozoic basement, but rests unconformably on various members of the Jurassic section.

Rhine Graben. Before its formation, this Jurassic belonged to the sedimentary covering of the Vosges–Black Forest Massif and established the continuity

between the Paris basin, in the west, and the German basins, in the east.

Alsace has produced, from the beginning, about 20 million brl of oil, *i.e.* more than has been produced by the rest of France altogether. And what is still more important—the foregoing statement having chiefly an historical value—Alsace is the French oil province where the evidences of hydrocarbons are the more numerous, and, geographically and stratigraphically, the most widely scattered.

But this fact has an unfavourable counterpart: the oil pools are generally of small volume, and their production is barely profitable.

This concerns chiefly the Pechelbronn oilfield, where the oil is scattered in Oligocene sand lenses. Oil has been produced from different Mesozoic horizons, but it was for a long time considered that oil had its origin in the Tertiary formations, from where it had migrated into the Mesozoic formations by reason of numerous and important faults known in that region.

This theory has once again been questioned through the Staffelfelden discovery, some years ago, of a small pool in the Middle Jurassic of the southern Alsace, 6500 ft deep, and developed during 1953–54. The communication between the Mesozoic and Tertiary formations seems here to be most improbable. Afterwards, oil was discovered in the formations of the same age and of the same facies in the Paris basin, which until Tertiary times was joined to the Alsace basin. That oil is certainly of pre-Tertiary origin, and the fact discredits definitively the theory of a Tertiary origin common to all the oils of the Rhine graben.

Though the development of the Staffelfelden oilfield remained rather disappointing, as the daily output did not exceed 750 brl, and the recoverable reserves were of the order of 450,000 brl only, its discovery provoked during the two last years a steady exploration activity, directed towards pre-Tertiary objectives and chiefly to the Middle Jurassic. This activity was not limited to the neighbourhood of Staffelfelden, but was extended to the whole southern Alsace, and afterwards to the central Alsace. As to the northern Alsace, it did not need such encouragement, because of the small pools and numerous oil shows found in different members of the Mesozoic section.

Up to a very recent date the different wildcats which were drilled remained quite disappointing, as no other pools have been discovered, notwithstanding occasional important oil showings coming from the Middle Jurassic.

However, two results obtained in the last months of 1955, the economic significance of which cannot yet be determined, seem to open a new way to the exploration. Six miles south of Staffelfelden a wildcat has found oil at 5300 ft. The producing horizon of Upper Jurassic age is situated at 600 ft approximately, above the top of the Middle Jurassic. Though this oil is trapped in a structure of slight closure, the fact that this Upper Jurassic horizon is missing at Staffelfelden, where it was quite eroded before the deposit of the Tertiary, suggests the idea that the truncation of the reservoir must influence the localization of the pool. The whole of the Upper Jurassic is dipping slightly towards the south, beneath the Tertiary unconformity. It will be interesting to explore the truncated edges of the Jurassic formations.

It has been known for a long time that a similar occurrence exists under the Tertiary unconformity in northern Alsace. Here, the Middle and the Lower Jurassic are progressively truncated by the unconformity from the south to the north. A wildcat located quite recently 10 miles south of Pechelbronn, to explore the edge of the Middle Jurassic, gave good oil shows immediately below the pre-Tertiary unconformity, 4800 ft deep.

So, it is probable that at the north, as well as at the south of Alsace, the exploration of the Mesozoic, could be directed in such a way that structural factors would not play an exclusive part.

The exploration of the Tertiary, which has been somewhat abandoned during recent years, has still benefited from the data given by the wells drilled on Mesozoic prospects. In this way, a small oilfield has been discovered at Donau, 10 miles south-east of Pechelbronn; nine of the fourteen wells which have been drilled are now producing approx 180,000 b.d.

CONCLUSION

On completion of this review of the main aspects of oil exploration in Metropolitan France and of the efforts it has more particularly raised during the past two years, it is interesting to examine the trends followed by these efforts and to establish a parallel between them and the progression of the results obtained.

Oil Production Compared with Exploration Activity

It would seem that the best method to do this is to compare the total annual expenses in proportion to the reserves of hydrocarbons discovered. These two parameters, however, and particularly the second one, do not permit an easy and precise estimate. The first one has therefore been replaced by a double association, which seems adequately to represent the efforts carried out:

(*a*) total metres drilled annually;
(*b*) annual seismic activity estimated in crew-months.

On the other hand, in place of the evolution of the discovered reserves, that of oil production (plus condensate) can be considered.

Interpretation of the three curves (Fig 8) should be made with caution, as they involve extremely varied elements.

Especially, although the impulse given to the exploration activities following discovery of the Parentis oilfield is evident, the results of the preceding discovery at Lacq on the drilled metres curve are in part con-

cealed by the increase resulting from the execution in 1950 of a complementary programme of equipment changes. These were intended to replace the old units by modern ones and to better adapt the existing facilities with respect to the importance of the problems to be solved.

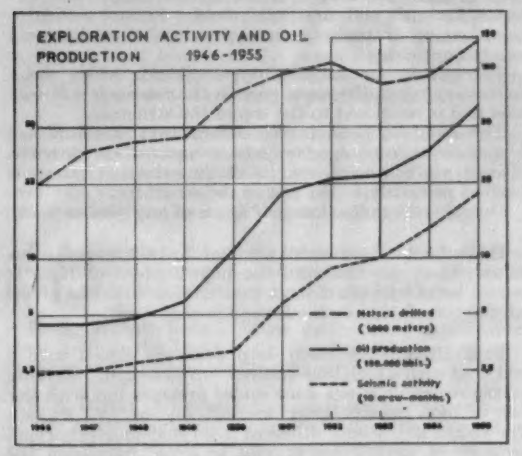

FIG 8

On this same curve the very appreciable decrease which characterized the year 1953 results from a number of technical and financial factors.

Oil and Gas Reserves

Although the reserves cannot be entirely calculated, Table I gives an estimate as at the end of 1955.

TABLE I

Basin	Field	Producing formation	Oil (1000 brl)	Gas (Mcf)
Aquitaine	Parentis	Lower Cretaceous	113,200	
	Mothes	Lower Cretaceous	?	
	Lacq { Upper pool	Upper Cretaceous	7900	
	Lacq { Lower pool	Lower Cretaceous		?
	St Marcet	Upper Cretaceous		140,000
Alsace	Pechelbronn	Oligocene	400 (?)	
	Donan	Oligocene	300	
	Staffelfelden	Middle Jurassic	70	

This table shows the double predominance of Cretaceous and more particularly of Lower Cretaceous as an oil objective; and of the "Aquitaine basin" as an oil province.

Future of Oil Exploration in France

For the future, various forecasts can be made safely; they are the following:

(1) Increase of production and of the reserves figure as regards Parentis and Mothes oilfields. The production at Parentis, in 1956, will probably be over 7 million brl.

(2) Reduction of production in the Lacq upper oil pool, the decline of which, previously foreseen, started in the course of 1954.

(3) Putting into production of the Lacq lower gas pool and first estimate of reserves. Beginning of regular production is foreseen for the middle of 1957 on the basis of 35 million cu. ft/day.

But the future of French oil production will be, above all, determined by the new discoveries for which one can rightly hope. As a matter of fact, the extensive impulse given to oil exploration during the past two years is far from having had its full effect. To ascertain this, it is sufficient to look at the map of exploration permits. At the end of 1955 the area covered by the applications for permits covered approximately half that of the permits already granted. Furthermore, a certain number of applications have been made by newcomers to Metropolitan France. Taking into consideration the work commitments which, in France, determine the granting of permits, a continued increase of activities can be expected during the years to come, forming part of the progress which started in 1953, and is reflected in the curves given above.

These reasons for optimism are reinforced by geological considerations arising from the promises brought forward by the results already obtained and from the fact that a large part of the French sedimentary areas are still barely explored or even totally unexplored.

This is particularly the case for:

(1) the southern and northern areas of the Paris basin;

(2) the northern and NE. areas of the Aquitaine basin;

(3) several areas of the Rhone basin: Valence basin, Northern Bresse, Central Jura, and Provence.

On the other hand, the objectives which may eventually exist in the Paleozoic formations folded during the Hercynian orogeny, but non-metamorphosed, remain practically untouched.

In these various prospects the coming years will probably bring some promising results.

ACKNOWLEDGMENTS

The author expresses his gratitude to all the French Research Organizations, data from whom have supplied the elements of this study. They have put at his disposal their entire results. Several of the diagrams are reproductions of material furnished by these organizations.

References

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DISCUSSION

R. P. Walters: You will be impressed by the great amount of work going on in France. The French may have been late in getting exploration work started, but they are making up for lost time now. Developments over the next few years should prove whether there are to be important producing areas outside the Aquitaine basin, and also whether this basin is to be a really important producer. As Mr Hirtz pointed out, there are two gas fields and three oilfields. Only one of the oilfields can be called a major, namely Parentis. It is not thought, however, that France will prove to be like Poland and have only one major field.

The author has told you in general about Parentis, but I might add a few words. It is a limestone field which is in part dolomitized. The porosity is closely related with the dolomitization, and the dolomitization related with the structure. The reservoir limestone series, which extends from the Lower Cretaceous into the Jurassic and has an undetermined thickness, contains an oil column of 1475 ft. Of this amount as much as 35 per cent may be porous in the axial wells, where the dolomitization reaches its highest point of the section.

The decrease in porosity away from the axis is very rapid. Well No. 4, 4600 ft north of the highest part of the structure, is a good example. This well has such a thin porous section that it will flow at a rate of only 60 b.d., whereas the crestal wells will make several thousand brl. Well No. 10, a little over 2 miles east of this same crest but more in the direction of the plunge of the anticline, had no porosity in the first 700 ft. On the south flank, our control is not as good, but the indications are that dolomitization will be found to occur higher along it than on the north flank. This may be related to a major longitudinal fault, with a throw of 1000 ft which occurs there.

The productivity index also varies greatly, ranging from less than one brl per pound drop in pressure to as high as 1675 brl. To date the field has produced 7,500,000 brl, and the present rate is 19,000 b.d. from thirteen wells. The limits of the field have not been fully determined, but wells to be drilled during 1956 should give a fair definition of the extent of the productive area.

G. W. Halse: Is the Parentis reservoir composed entirely of the cavities due to dolomitization of the limestone, or do fissures also make a contribution to production?

R. P. Walters: The limestone is fractured, and this fracturing certainly contributes to production. The amount of fracturing, like that of dolomitization, is related to structure and diminishes away from the axis. However, the vugular porosity is in all probability more important. In several cases, the drillers have reported free drops of the bit of 6 inches or more, and in one case, in the discovery well, there was a free drop of over 3 ft.

E. C. Masterson: What is the production behaviour of the Parentis wells? Do they show slow or rapid declines?

R. P. Walters: The Parentis wells show relatively slow declines. The pressure drop is uniform throughout the field, i.e. when new wells come in, they have the same pressure as existing wells. There has been a pressure drop of about 25 lb/1 million brl.

F. A. Nichols Roth: Is there a comparison for the Parentis field? Does it resemble the Polish fields which have been mentioned?

P. S. Hirtz: There is definitely no comparison between Parentis and any Polish field. Poland was mentioned as an example of an oil province which has only one major field.

Parentis is an anticlinal-type oilfield, where dolomitization plays the main part in the reservoir's formation and is restricted to the top of the structure.

The Lacq oil pool, in the dolomitized limestones of Upper Cretaceous age, may be compared to Parentis. Recent studies have confirmed that dolomitization is limited primarily to the top of the structure.

Outside of France, I do not know of any similar field.

H. D. Lack: In view of the high formation pressures in the Lacq gas field and the high content of H_2S, it would be of interest if some information could be given on the completion methods used in that field.

P. S. Hirtz: The Lacq deep wells are drilled with a red mud with a high lime content (up to 30 g/l). Drilling in the reservoir is not done under pressure but with the use of high density mud (around 2·0—or 16·7 lb/gal). Its weight is not very different from that of overburden, so a strict equilibrium is kept to avoid fracturing the formation and loss of circulation, as well as a blow-out.

The 9⅝-inch casing is set after drilling through porous dolomite (zone of lost circulation), which overlies the cap rock of the gas pool. The 7-inch casing is set at the top of the pay formation, and the producing section is left uncased. For safety reasons, two strings of coaxial tubing are used for production. The diameters actually used are 4 inch and 2⅜ inch, but these could be increased in the future to obtain a better producing rate. A string of 5½-inch casing is hung from the Christmas tree to allow eventually the heating of the tubing to prevent its corrosion by hydrates. As such an operation has not been required up to now, the necessity of the 5½-inch casing is under discussion. All the annular spaces are closed by " D " Baker packers.

The tubing strings are made of highly resistant steel, N. 80–APS–10M4, especially developed in France for the purpose, as is also the type of tool joint.

An inhibitor, Kontol, is used to prevent H_2S corrosion.

The solution of the difficult problem of corrosion appears to have been successful. Iron dosing made in water condensed from the gas produced showed a lower proportion than the American tolerances.

R. P. Walters: What is the explanation of the origin of the oil in the Upper Cretaceous in Lacq?

P. S. Hirtz: The Lacq oil pool appears to be a hinge-line pool. During Upper Cretaceous time, Lacq was located immediately to the north of a deep trough which extended along the foot of the growing chain of the Pyrenees.* In that " Aturian trough " a thick series of flysch facies was deposited, more than 6000 ft in the Pau area.

Towards the north, on the shelf, the Upper Cretaceous section of epi-continental type, mainly limestones, is thinner, 1500 ft in Lacq.

The Cretaceous flysch has several characteristics of the usual petroliferous series. Many wells drilled in it

* " La Géologie de l'Aquitaine et ses Possibilités Pétrolifères." Y. Gübler *et al.* *Proc. Third World Petrol. Congr.*, 1951, Section 2A.

have found oil and very frequent gas shows. However, the whole flysch is tight, with a general lack of reservoirs.

It is thus thought that the hydrocarbons of the Cretaceous flysch accumulated into pools only through interfingering with reservoir formations. It is the case along the northern border of the "Aturian trough," where Upper Cretaceous flysch grades into a limestone series.

This favourable situation, which occurs at Lacq, was reinforced by the intervention of an orogenic phase at the end of the Upper Cretaceous which determined an early structural trap. At the present time, that phase seems to be restricted to the Lacq structure, which therefore appears to have had a privileged history.

J. H. Taylor: In regard to the close connexion between structure and sedimentation in the Aquitaine basin, are there any instances in which the absence of a cap rock over the crest of an anticline can be related to the influence of the growing fold upon sedimentation?

R. P. Walters: We really know too little about the area to be able to answer. After all, relatively few wells have been drilled, and there is much to be learned.

F. A. Nichols Roth: What methods of exploration were used in the Paris basin to reach the arrived conclusion, and was core drilling employed?

P. S. Hirtz: All exploration methods have been used in the Paris basin, and all created difficulties. Surface geology is of restricted use in many areas due to the lack of outcrops and, still more, the lack of key horizons in several members of the stratigraphic section, *e.g.* Upper Cretaceous chalk.

Core drilling has proved to be very effective in the eastern part of the basin where good lithologic markers are present in the Lower Jurassic. In the central part of the basin, however, due to the slight unconformity between Cretaceous and Jurassic, core drilling should reach the top of Jurassic, which is rather deep. That method has been considered too expensive.

As far as geophysical prospecting is concerned, the gravity meter has been of some use. As the whole basin is rather flat, however, anomalies from the sedimentary section remain minor and are often concealed by the main anomalies from the heterogeneous basement.

Seismic prospecting has been and is still intensively used. The two main difficulties encountered are first, bad surface conditions, particularly on the Cretaceous chalk which absorbs the main part of the energy, and on the Tertiary limestones plateaux. Refraction was tried to overcome these difficulties, but its accuracy appears to be generally too poor in respect to the structural conditions.

The second difficulty is the smallness of the structural closures, which demands extreme accuracy in measurement. Speed variations which are known inside several formations can conceal the slight anomalies of structural origin or indicate pseudo-structures.

R. P. Walters: Might we have some information on how the French Government provides for depletion allowance?

P. S. Hirtz: The French depletion allowance gets its inspiration from American legislation. Its purpose is to allow the oil operators to explore for new fields able to replace those which are declining.

With that in view, the financial law foresees the setting up of a special reserve when establishing the income tax. The maximum amount of that reserve, which cannot exceed 50 per cent of the net profit of exploration from which it is reduced, is 27·5 per cent of the value of the products obtained.

E. C. Masterson: What royalties are paid to the Government?

P. S. Hirtz: The royalties paid were instituted in October 1955, and are fixed at the following rate:

TABLE A

	Fraction of yearly total production	% of value of production
	metric tons	
Crude oil	Under 50,000	0
	50,000– 100,000	6
	100,000– 300,000	9
	300,000–1,000,000	12
	Over 1,000,000	14
	million cubic metres	
Natural gas	Under 300	0
	Over 300	5

The payment is either in kind or in money for crude oil, the choice being left to the Government. It is always in money for gas.

At the present time, no concession exists under that legislation.

The Parentis concession has not yet been granted and Esso REP was authorized by governmental decision to begin producing before any grant was made.

E. C. Masterson: Are the royalties affected by any changes in Government?

P. S. Hirtz: Fortunately no.

The meeting closed with a unanimous vote of thanks to the speaker.

SOLUTION GAS DRIVE *

By M. A. KIRKBY † and J. BIRKS † (Fellow)

SUMMARY

A method of calculating solution gas drive performance of a reservoir, based on the P-V-T oil–gas characteristics and the relative permeability curve for the rock, is described in this paper and illustrated by a table and graphs. It is considered suitable for general application.

For purposes of illustration, two typical fissured limestone reservoirs have been studied, and it is shown that the efficiency of gravity drainage can be calculated by comparing the gas dome oil recovery efficiency, as determined by material balance, with the solution gas drive data. The production policy to be followed for maximum recovery of oil, pressure maintenance or pressure depletion, may be decided by the magnitude of the computed gravity drainage effect.

NOMENCLATURE

B_o = oil formation volume factor.
B_w = water formation volume factor.
G_p = cumulative production of gas (cu. ft. at S.T.P.).
ΔG_p = production of gas during a pressure reduction (cu. ft. at S.T.P.).
K_{rg} = relative permeability to gas.
K_{ro} = relative permeability to oil.
N_p = cumulative production of stock tank oil (cu. ft.).
ΔN_p = production of S.T. oil during a pressure reduction (cu. ft.).
p = reservoir pressure (p.s.i.a.).
R = producing gas–oil ratio (cu. ft. at S.T.P./cu. ft. S.T. oil).
R_s = volumes of solution gas (at S.T.P.)/vol. of S.T. oil.
S_g = fractional gas saturation.
S_o = fractional oil saturation.
S_w = fractional water saturation.
v_g = relative volume of gas at reservoir pressure and temperature.
ΔV_T = total expansion of all fluids in the rock during a pressure reduction.
V_p = pore volume of reservoir under consideration.
μ_g = viscosity of gas at reservoir conditions (cP).
μ_o = viscosity of oil at reservoir conditions (cP).
Subscripts: i = initial.
1, 2, . . . n . . . refer to subsequent expansion steps; av refers to conditions at the average pressure during a finite pressure reduction.

INTRODUCTION

SOLUTION gas drive is the process of recovery by which oil is expelled from the pores of the rock due to the release of gas from solution in the oil as the reservoir pressure falls. The process is similar to that of a gas drive by gas injection, except that the gas is generated internally in the rock pores. Since a low viscosity gas is displacing a much higher viscosity oil, the efficiency of oil recovery by this process alone is low.

In an oil reservoir, gas released low in the structure will migrate to higher points in the reservoir and an equivalent volume of oil will drain down to take its place. This process of gravity segregation of gas and oil is usually called "gravity drainage," and the amount of drainage depends principally on the permeability of the rock. Solution gas drive combined with good gravity drainage will give high efficiencies of oil recovery.

Where reservoir conditions are suitable for good gravity drainage, the reservoir pressure should be maintained by injecting gas into the crest of the structure, since a gas cap drive would be more efficient than one principally of solution gas drive. However, in low permeability formations, where gravity drainage is very small, since the efficiency of oil recovery by solution gas drive is increased by decreasing the reservoir pressure, it would be necessary to reduce the reservoir pressure considerably by producing excessive volumes of gas in order to recover the maximum quantity of oil. These alternative methods of reservoir operation are, of course, directly opposed to each other, and it therefore becomes necessary in a particular reservoir to determine the effectiveness of gravity drainage early in its producing life.

The solution gas drive performance of a reservoir can be calculated from the characteristics of the reservoir oil and gas and the relative permeability curve for the reservoir rock. Unfortunately, the gravity drainage term cannot be calculated directly, due to the uncertainties of flow paths and pressure gradients in the reservoir. However, the total oil recovery efficiency from the gas cap can be calculated by a material balance method; hence, by difference, the gravity drainage component can be determined.

This paper describes, first, a method of calculating solution gas drive performance, and secondly, the application of the method to the study of two oilfields, in one of which there is negligible gravity drainage, and in the other of which gravity drainage is an important process of oil recovery.

In this discussion the water drive contribution to oil recovery is not considered; where this is small, or of a lower efficiency than gravity drainage, it will not affect the argument.

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PART I. CALCULATION OF SOLUTION GAS DRIVE

The principles of solution gas drive performance have been described by Muskat [1] and Pirson.[2] The method described here applies to a tabular form of calculation where the intervals of pressure-drop below the original saturation pressure are suitably chosen and the values of oil recovery and producing gas–oil ratio are calculated in stages by columns. In the derived equations steady state conditions are assumed to exist throughout the reservoir volume considered, and no allowance is made for the expansion or production of interstitial water; this factor, however, is discussed later.

NATURE OF THE PRODUCTION PROCESS

If some of the fluids of a closed reservoir are removed, the pressure in the reservoir will fall. This represents cause and effect in the production of oil, but in an analysis of the process it is easier to consider the order of events reversed. A drop in pressure of the contents of the rock then allows the contents to expand, which means that fluids equal in volume to the amount of the expansion must flow out from the rock. The relative permeability of the rock to the fluids (oil, gas, and water), and the viscosities of these fluids, will determine their proportions in the effluent stream.

The analysis may be broken down to two operations;

(1) Consider the pressure as falling in a suitable number of stages between the initial and final reservoir pressure and calculate the expansion of the fluids in the rock due to the pressure drop for each stage.

(2) Equate this expansion of fluids to the volume of all fluids produced during the pressure drop and calculate the produced volume of each individual fluid from the relative mobilities of the fluids.

CALCULATION OF EXPANSION

It is frequently justifiable to neglect the part played by interstitial water in the expansion of rock fluids during a solution gas drive. S_g and S_o may then be considered as the fractional gas and oil saturation of the hydrocarbon-filled pore volume of the rock, and fluid expansion with pressure drop will be due to (1) saturated oil and (2) free gas.

It is proposed to consider the pore volume V_p that initially contains unit stock tank volume of oil. Then

$$V_p = B_{o,i}/S_{o,i}$$

$S_{o,i} = 1{\cdot}0$ if there is no original gas saturation in the reservoir.

A solution gas drive reservoir after its initial expansion will always contain some free gas, which will expand as the pressure drops. It is necessary to consider separately the expansion of the saturated oil and the free gas during a drop in pressure.

Suppose the reservoir has been depleted to pressure p_n, leaving an oil saturation $S_{o,n}$ and a free gas saturation $S_{g,n}$. The pressure is then dropped to p_{n+1}.

Expansion of Saturated Oil

The expansion of the saturated oil is equal to the volume of gas liberated between pressures p_n and p_{n+1}, minus the accompanying shrinkage of the oil.

Stock tank oil in rock at pressure p_n

$$= (1 - N_{p,n})$$

Shrinkage due to pressure drop

$$= (B_{o,n} - B_{o,n+1})(1 - N_{p,n})$$

Volume of gas liberated

$$= (R_{s,n} - R_{s,n+1})v_{g,n+1}(1 - N_{p,n})$$

$\therefore$ Expansion of saturated oil

$$= (1 - N_{p,n})[(R_{s,n} - R_{s,n+1})v_{g,n+1} - (B_{o,n} - B_{o,n+1})] \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Expansion of Free Gas

Reservoir volume of free gas existing at p_n

$$= S_{g,n} \cdot \frac{B_{o,i}}{S_{o,i}}$$

S.T.P. volume of free gas existing at p_n

$$= S_{g,n} \cdot \frac{B_{o,i}}{S_{o,i}} \cdot \frac{1}{v_{g,n}}$$

Reservoir volume of this gas at p_{n+1}

$$= S_{g,n} \cdot \frac{B_{o,i}}{S_{o,i}} \cdot \frac{v_{g,n+1}}{v_{g,n}}$$

$\therefore$ Expansion between p_n and p_{n+1} of free gas existing at p_n

$$= S_{g,n} \cdot \frac{B_{o,i}}{S_{o,i}} \left[\frac{v_{g,n+1}}{v_{g,n}} - 1 \right] \quad . \quad . \quad (2)$$

Total expansion of reservoir fluids between p_n and p_{n+1}

$$= \Delta V_T = (1) + (2)$$

CALCULATION OF RELATIVE FLOW RATES OF GAS AND OIL

Under any given saturation conditions, the relative rates of flow of gas and oil are determined by the ratio K_{rg}–K_{ro} of the rock at that saturation, and by the viscosities of the oil and gas, according to the simple relationship in equation (4) below.

For any drop in pressure, $p_n \longrightarrow p_{n+1}$, the sum of the volumes of flowing oil and gas (at reservoir pressure and temperature) is equal to the expansion ΔV_T.

The saturation conditions at the start of the expansion will be known, but the final oil saturation cannot be determined until the volume of oil produced during the expansion is known. The calculation of this quantity in turn demands a knowledge of the average oil saturation during the expansion (to define the average K_{rg}–K_{ro}). A method of successive approximation is therefore needed, and the adopted approach is as follows;

(1) Estimate the final oil saturation $S_{o,n+1}$ after the expansion. If a graph of saturation *v.* pressure is drawn as the calculation proceeds, it is possible to make quite an accurate estimation.

(2) Find the values of K_{rg}–K_{ro} and μ_o–μ_g at the average estimated rock saturation and pressure by reference to the graphs of rock and oil characteristics.

(3) The flowing quantities of oil and gas are found from the relations

$$\Delta G_p \cdot v_{g,n+1} + \Delta N_p \cdot B_{o,n+1} = \Delta V_T \quad . \quad (3)$$

and

$$\frac{\Delta G_p \cdot v_{g,\mathrm{av}}}{\Delta N_p \cdot B_{o,\mathrm{av}}} = \left(\frac{K_{rg}}{K_{ro}}\right)_{\mathrm{av}} \cdot \left(\frac{\mu_o}{\mu_g}\right)_{\mathrm{av}} \quad . \quad (4)^*$$

Combining equations (3) and (4) gives

$$\Delta N_p = \frac{\Delta V_T}{\left[B_{o,n+1} + \frac{v_{g,n+1}}{v_{g,\mathrm{av}}} \cdot \left(\frac{K_{rg}}{K_{ro}}\right)_{\mathrm{av}} \left(\frac{\mu_o}{\mu_g}\right)_{\mathrm{av}} \cdot B_{o,\mathrm{av}}\right]}$$

If small intervals of pressure reduction are considered, the difference between B_{n+1} and B_{av} is very small (*e.g.* $< 0{\cdot}2\%$) and the equation may be written

$$\Delta N_p = \frac{\Delta V_T}{B_{o,n+1}\left[1 + \left(\frac{v_{g,n+1}}{v_{g,\mathrm{av}}}\right) \cdot \left(\frac{K_{rg}}{K_{ro}}\right)_{\mathrm{av}} \left(\frac{\mu_o}{\mu_g}\right)_{\mathrm{av}}\right]} \quad (5)$$

Where shrinkage over the intervals of pressure drop is large enough to introduce an undesirable error, equation (5) will apply so long as

$$\left(\frac{K_{rg}}{K_{ro}}\right) \cdot \left(\frac{\mu_o}{\mu_g}\right) \ll 1$$

When $\left(\frac{K_{rg}}{K_{ro}}\right) \cdot \left(\frac{\mu_o}{\mu_g}\right) \gg 1$, it is more accurate to use

$$\Delta N_p = \frac{\Delta V_T}{B_{o,\mathrm{av}}\left[1 + \left(\frac{v_{g,n+1}}{v_{g,\mathrm{av}}}\right)\left(\frac{K_{rg}}{K_{ro}}\right)_{\mathrm{av}}\left(\frac{\mu_o}{\mu_g}\right)_{\mathrm{av}}\right]} \quad (6)$$

(4) The final saturation, resulting from the production of ΔN_p, is calculated;

$$(1 - N_{p,n+1}) = (1 - N_{p,n}) - \Delta N_p$$

$$S_{o,n+1} = \frac{(1 - N_{p,n+1})B_{o,n+1}}{V_p}$$

$$= B_{o,n+1}(1 - N_{p,n+1})\frac{S_{o,i}}{B_{o,i}}$$

If $S_{o,i} = 1$

$$S_{o,n+1} = \frac{B_{o,n+1}}{B_{o,i}}(1 - N_{p,n+1});$$

and $$S_{g,n+1} = (1 - S_{o,n+1})$$

Reference to the relative permeability graph will indicate whether the estimated value of S_o is close enough to the calculated value to make a further approximation unnecessary.

CALCULATION OF PERCENTAGE OIL RECOVERY

The total stock tank oil N_p recovered by a reduction in pressure from the initial pressure p_i to p_n is given by the summation of the values of ΔN_p,

$$N_p = \sum_{p_i}^{p_n} (\Delta N_p) \quad . \quad . \quad . \quad . \quad (7)$$

Since the original oil in place considered was a unit stock tank volume, the percentage recovery of the original oil in place is $(100\ N_p)$.

CALCULATION OF GAS–OIL RATIOS

From equation (3),

$$\Delta G_p = (\Delta V_T - B_{o,n+1} \cdot \Delta N_p)/v_{g,n+1}$$

and wellhead G.O.R.

$$= R = R_{s,\mathrm{av}} + (\Delta G_p/\Delta N_p) \quad . \quad . \quad (8)$$

REFINING THE CALCULATIONS

It should be noted that there is a source of error which has not been allowed for in the present treatment. The composition of the gas released from the oil changes as the pressure drops; consequently the compressibility factor of the gas in the reservoir must also change with pressure. The change in deviation factor of the evolved gas will, however, be greatest at low pressures, where its effect on the calculated quantity of produced oil will be minimized. Further, the low-pressure performance of the reservoir will in any case deviate most from the theoretical, due to variations in lithology, drainage, etc. However, if the deviation factor of the gas coming out of solution over each pressure interval is known, a correction for this factor can be made. This will involve the assumption that as a volume of gas is liberated from the oil, equal (at reservoir conditions) to the volume of free gas existing in the pores at the time, it will displace this free gas at some known efficiency. The deviation factor of the gas remaining in the pores can then be deduced. It is considered that it will be very rarely necessary to make this correction. If a record has been kept of the deviation factor of the produced gas

* All the values in equation (4) are at the average pressure $(p_n + p_{n+1})/2$.

over the life of the field to date, this information should be used.

Unless the interstitial water saturation of the reservoir is high, the expansion of this water will have little effect on the solution gas drive. The two phenomena of interest are the change in hydrocarbon pore-volume due to volume change of the water, and evolution of gas from the water. P–V–T and solubility data for brines [3] indicate that even a 10° API oil will contain more than ten times the gas, volume for volume, than will associated brines, and of course, the volume of oil may be several times the volume of brine. A 30° API oil at 4000 p.s.i. will contain about fifty times as much gas as will brine (at normal reservoir temperatures). As for change in volume of the water, it is shown that a brine of 30,000 p.p.m. salinity at 200° F increases in volume by 0·2 per cent when the pressure is lowered from 3000 to 2000 p.s.i.

To allow for the effect of the brine solution gas the total expansion of fluids ΔV_T during a pressure drop should be increased by the amount

$$(R_{sw,n} - R_{sw,n+1})\left[\frac{B_{o,i}}{S_{o,i}} \cdot \frac{S_{w,i}}{B_{w,i}}\right] \cdot v_{g,n+1}$$

where R_{sw} is the volume of gas in solution in the water and the term in square brackets is the stock tank volume of water in the rock volume under consideration.

Making allowance for the change in volume of the brine will involve adjusting the expansion $V\Delta_T$, and also the hydrocarbon pore volume, and hence the oil and gas saturations.

The effect of gas in solution in the brine will be to increase slightly the recovery of oil in the initial stages of the expansion, when the permeability to gas is low. Thereafter the amount of this excess produced oil will gradually decrease to a final small value, as the reservoir nears depletion. The expansion of the interstitial water will increase the oil recovery by a small amount.

EXAMPLE OF SOLUTION GAS DRIVE CALCULATION

The following data on the properties of the reservoir oil and gas and reservoir rock are required in graphical form:

(1) Formation volume factor of the oil *v.* saturation pressure.

(2) Viscosity of the reservoir oil *v.* saturation pressure.

(3) Gas dissolved in the reservoir oil *v.* saturation pressure. (Units of cubic feet of gas at 1 atm pressure and 60° F/cu. ft. of stock tank oil.)

(4) Deviation factors (Z) for the dome gas *v.* pressure.

(5) Viscosity of the gas *v.* pressure. These viscosity values may be calculated from the data of Carr *et al*,[4] which relate gas viscosity with gas specific gravity, pressure, and temperature.

(6) The relative volume v_g of the reservoir gas *v.* pressure. This may be calculated from the expression $v_g = Z \frac{14{\cdot}7}{p} \cdot \frac{(460+t)}{520}$, where p is the pressure in p.s.i.a., and t is the reservoir temperature in ° F.

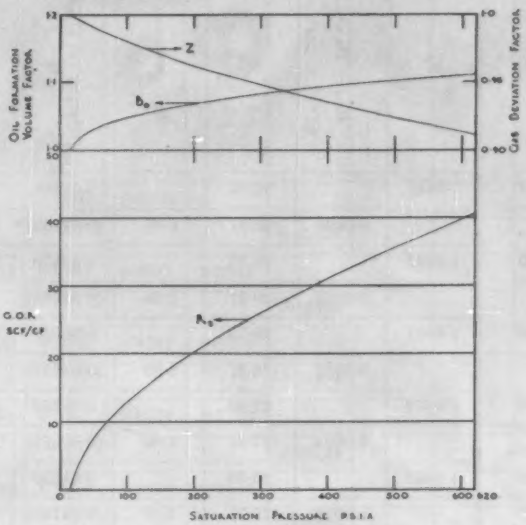

Fig 1

F.V.F., GAS DEVIATION FACTOR, AND GAS SOLUBILITY *v.* SATURATION PRESSURE

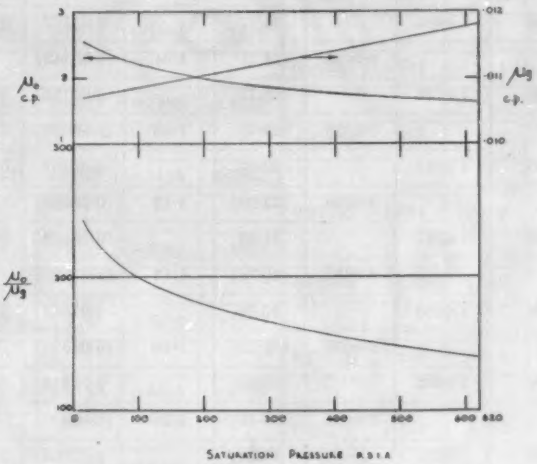

Fig 2

OIL AND GAS VISCOSITIES *v.* SATURATION PRESSURE

(7) Relative permeability ratio of gas to oil *v.* oil saturation, expressed in this case as a percentage of the hydrocarbon filled pore space.

For illustration, the data have been plotted in Figs 1 to 3 for an oil which had an original saturation pressure of 620 p.s.i.a. (from oilfield No. I).

In the example shown in Table I it was assumed

TABLE

Solution Gas Drive Calculation for a

	← Expansion of Oil and Free Gas →											
1	2	3	4	5	6	7	8	9	10	11	12	13
P	B_o	$B'_{o,n} - B_{g,n+1}$	R_i	$R_{i,n} - R_{i,n+1}$	Relative vol of gas v_g	5×6 Vol of evolved gas per vol S.T.O.	$7 - 3$ Expansion of oil per vol S.T.O.	$\frac{v_{g,n+1}}{v_{g,n}} - 1$	$S_{g,n} \times B_o$	9×10 Expansion of free gas	$8\,(1 - N_{p,n})$ Expansion of oil	$11 \overset{1}{+} \overset{2}{\Delta V_r}$
400	1·0942		30·74		0·03666				0			
		0·0020	(30·2) *	0·97	(0·03768)*		0·03554	0·0556		0	0·03554	0·03554
380	1·0922		29·77		0·03870	0·03754			0·03753			
		0·0021	(29·3)	0·98	(0·03983)		0·03804	0·0584		0·00219	0·03680	0·03899
360	1·0901		28·79		0·04096	0·04014			0·07856			
		0·0022	(28·3)	0·99	(0·04219)		0·04086	0·0620		0·00487	0·03807	0·04294
340	1·0879		27·80		0·04350	0·04306			0·12354			
		0·0024	(27·3)	1·00	(0·04493)		0·04396	0·0657		0·00812	0·03922	0·04734
320	1·0855		26·80		0·04636	0·04636			0·17310			
		0·0025	(26·3)	1·01	(0·04799)		0·04761	0·0701		0·01213	0·04040	0·05253
300	1·0830		25·79		0·04961	0·05011			0·22770			
		0·0026	(25·3)	1·02	(0·05145)		0·05176	0·0742		0·01690	0·04141	0·05831
280	1·0804		24·77		0·05329	0·05436			0·27311			
		0·0028	(24·3)	1·04	(0·05542)		0·05705	0·0799		0·02182	0·04336	0·06518
260	1·0776		23·73		0·05755	0·05985			0·29894			
		0·0029	(23·2)	1·08	(0·06003)		0·06461	0·0862		0·02577	0·04768	0·07345
240	1·0747		22·65		0·06251	0·06751			0·31535			
		0·0030	(22·09)	1·12	(0·06550)		0·07363	0·0945		0·02980	0·05336	0·08316
220	1·0717		21·53		0·06842	0·07663			0·32881			
		0·0032	(20·94)	1·18	(0·07205)		0·08591	0·1040		0·03420	0·06136	0·09556
200	1·0685		20·35		0·07552	0·08911			0·33997			
		0·0033	(19·72)	1·26	(0·08000)		0·10277	0·1150		0·03910	0·07255	0·11165
180	1·0652		19·09		0·08418	0·10607			0·35000			
		0·0035	(18·40)	1·38	(0·08990)		0·12767	0·1290		0·04515	0·08920	0·13435
160	1·0617		17·71		0·09505	0·13117			0·35966			
		0·0037	(16·96)	1·50	(0·10250)		0·15978	0·1470		0·05287	0·11054	0·16341
140	1·0580		16·21		0·10899	0·16348			0·36875			
		0·0040	(15·40)	1·61	(0·11850)		0·20127	0·1700		0·06269	0·13798	0·20067
120	1·0540		14·60		0·12750	0·20527			0·37794			
		0·0045	(13·75)	1·70	(0·14100)		0·25679	0·2050		0·07748	0·17451	0·25199
100	1·0495		12·90		0·15370	0·26129			0·38724			

* Figures in brackets are at the mean pressure.

I

400 p.s.i.a. Saturation Pressure Oil

← Oil Recovery →											← G.O.R. →			
14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
$\frac{K_{rg}}{K_{ro}}$	$\frac{\mu_o}{\mu_g}$	$\frac{v_{g,n+1}}{v_{g,n}}$	$\frac{B_{o,n+1}}{K_{rg}} \times \frac{\mu_o}{\mu_g} \times \frac{v_{g,n+1}}{v_{g,n}} \left(1 + \right)$	$13 \div 17$ ΔN_p	$\sum_{p_i}^{p_n}(\Delta N_p) = N_p$	Oil recovery $100\ N_p$ %	$1 - N_p$	$\frac{B_{o,n}}{B_{o,i}}$	21×22 S_o	$1 - S_o = S_g$	$B_{o,n+1} \times \Delta N_p$	$(13 - 25)/6$ ΔG_p	$26 \div 18$ $\frac{\Delta G_p}{\Delta N_p}$	$4 + 27$ Producing G.O.R. S.C.F./C.F.
							0	1·0000	1·0000	0				30·7
0	156	1·027	1·0922	0·03254							0·03554	0	0	30·2
					0·03254	3·25	0·96746	0·9982	0·9657	0·0343				
0	158	1·028	1·0901	0·03576							0·03899	0	0	29·3
					0·06830	6·83	0·93170	0·9963	0·9282	0·0718				
0	160	1·031	1·0879	0·03947							0·04294	0	0	28·3
					0·10777	10·78	0·89228	0·9942	0·8871	0·1129				
0	162	1·032	1·0855	0·04361							0·04734	0	0	27·3
					0·15138	15·14	0·84862	0·9920	0·8418	0·1582				
0	164	1·034	1·0830	0·04850							0·05253	0	0	26·3
					0·19988	20·00	0·80012	0·9898	0·7919	0·2081				
0·002	167	1·036	1·453	0·04013							0·04336	0·291	7·25	32·5
					0·24001	24·00	0·75999	0·9874	0·7504	0·2496				
0·010	169	1·038	2·970	0·02195							0·02365	0·749	34·1	57·4
					0·26196	26·20	0·73804	0·9848	0·7268	0·2732				
0·023	172	1·041	5·51	0·01333							0·01433	0·985	73·9	97·1
					0·27529	27·53	0·72471	0·9822	0·7118	0·2882				
0·035	175	1·045	7·94	0·01047							0·01122	1·098	104·9	127·0
					0·28576	28·58	0·71424	0·9794	0·6995	0·3005				
0·052	179	1·048	11·50	0·00831							0·00888	1·203	144·7	165·6
					0·29407	29·41	0·70593	0·9765	0·6893	0·3107				
0·070	182	1·052	15·37	0·00728							0·00775	1·298	178·2	197·9
					0·30135	30·14	0·69865	0·9735	0·6801	0·3199				
0·090	186	1·057	19·80	0·00680							0·00722	1·414	207·9	226·3
					0·30815	30·82	0·69185	0·9703	0·6713	0·3287				
0·116	190	1·063	25·85	0·00632							0·00669	1·529	241·9	258·9
					0·31447	31·45	0·68553	0·9669	0·6628	0·3372				
0·148	194	1·076	33·65	0·00595							0·00627	1·641	275·7	291·1
					0·32042	32·04	0·67958	0·9633	0·6546	0·3454				
0·180	200	1·090	42·30	0·00596							0·00626	1·743	292·4	306·2
					0·32638	32·64	0·67362	0·9591	0·6461	0·3539				

that the saturation pressure of the oil had fallen to 400 p.s.i.a. before the onset of gassing in the pores. Such a condition can happen in the oil zone of a fissured limestone field where gas in solution can

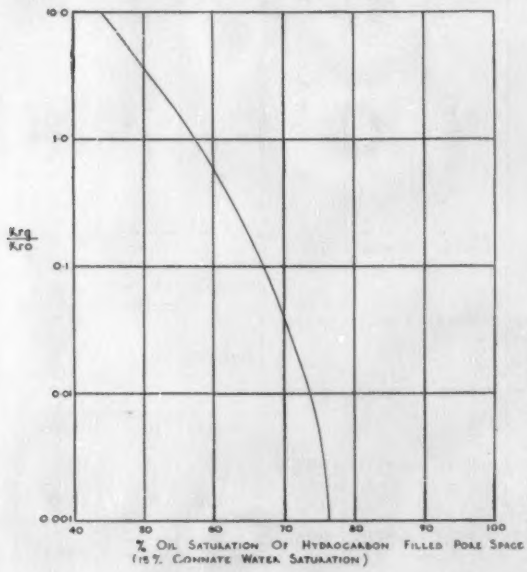

FIG 3

RELATIVE PERMEABILITY RATIO *v.* OIL SATURATION

diffuse out of the oil zone into the fissures, and thence by convection move to the lower pressure gas dome. The lower pressure case has been given simply because the method can be illustrated using fewer pressure intervals.

The rock was therefore assumed to be full initially with oil of saturation pressure 400 p.s.i.a., and since unit stock tank volume of oil was considered, the equivalent hydrocarbon volume to be expanded was $B_{o,i}$.

The method of using Table I is as follows:

(1) Select suitable pressure intervals and insert in Col 1.

(2) Enter the P–V–T data for the oil and gas in Cols 2–9, 15, 16, and 22, from the appropriate graphs.

(3) Initially there is no free gas and zero relative permeability to gas. Therefore the oil displaced will be equivalent to the expansion of the oil. Cols 10–13 are completed to give the expansion of the oil (and free gas). Cols 14–24 are completed to give the oil displaced, the residual oil, and the gas saturations. Cols 25–28 are completed to give the producing gas–oil ratio.

(4) Until the pressure has fallen to 300 p.s.i.a. there is zero permeability to gas and the oil displaced is equivalent to the expansion. At this stage the stock tank oil displaced is $N_p = 0{\cdot}19988$ (Col 19), or 19·988 per cent of the original oil in place (Col 20).

(5) Below 300 p.s.i.a. pressure the permeability to gas rises, *i.e.* K_{rg}–K_{ro} increases, and the oil expelled is less than the total expansion. At this stage the producing gas–oil ratio rises rapidly.

(6) At each stage of the calculation, for each pressure drop, the value of K_{rg}–K_{ro} equivalent to the mean oil saturation S_o (Col 23) read from figure should agree with that assessed in Col 14. If it does not, the values from Cols 14–23 should be refined until good agreement is obtained.

It should be noted in Table I that figures entered in the upper of the two spaces against each pressure refer either to values at the average pressure existing during an expansion, or to quantities involved in the expansion.

The results for the complete solution gas drive, starting with a 400-p.s.i.a. saturation oil, are shown in Fig 4, curves B. The solid curves give the variations between the pressure and percentage oil recovery, and the dashed curves show the variations in producing gas–oil ratios as the pressure falls from 400 p.s.i.a. to atmospheric pressure. Curves A show the results obtained by starting with a 620-p.s.i.a. saturation pressure oil.

One interesting feature which is not brought out in Fig 4 is that if a graph is plotted of percentage oil recovery *v.* the percentage fall in pressure below the

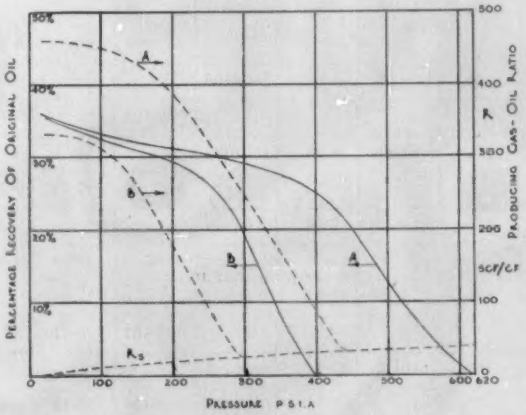

FIG 4

PERCENTAGE OIL RECOVERY AND PRODUCING GAS–OIL RATIO *v.* PRESSURE

A—curves for a 620-p.s.i.a. saturation pressure oil.
B—curves for a 400-p.s.i.a. saturation pressure oil.
Solid lines are percentage recovery curves.
Dashed lines are producing gas–oil ratio curves.

original saturation pressure, the curves for the 400- and 620-p.s.i.a. oils are almost identical. This means that the percentage oil recovery curve *v.* pressure can be easily computed for an oil with a saturation pressure between 400 and 620 p.s.i.a.

PART II. APPLICATION TO OILFIELD STUDIES

The comparison of the oil recovery by solution gas drive with that actually found by material balance from the gas dome can be best illustrated in the case of fissured limestone oilfields where the gas–oil levels can be measured accurately. In sandstone fields the gas–oil levels can usually be estimated only approximately by noting the producing wells going to gas.

In the two field cases studied the original saturation pressure of the oil in oilfield No. I was equivalent to the original reservoir pressure of 620 p.s.i.a. at the crest of the reservoir rock, and in oilfield No. II was equal to the dome pressure of the original small gas cap. As oil was produced from each field, the gas–oil level and the dome pressure fell approximately in proportion to the cumulative oil production. Furthermore, the saturation pressure of the oil in the oil column fell below the original saturation pressure due to diffusion of gas in solution from the oil zone and its transfer via the fissure system to the lower pressure gas dome. Thus the presence of free gas in the gas dome was due not only to solution gas drive on the oil originally in the gas dome, but also to the fall in saturation pressure of the oil in the oil column.

Taking these effects into account, the oil recoveries (1) by solution gas drive only, and (2) by material balance were calculated for oilfields No. I and No. II.

SOLUTION GAS DRIVE IN THE GAS DOME

For each period of production considered it was necessary to calculate the mean original saturation pressure of the oil above the gas–oil level at that time, because the saturation pressure of the reservoir oil was gradually decreasing with time. The gas dome pressure at the end of each period was known, and therefore the fall in pressure below the mean original saturation pressure was obtained by difference. Since the percentage fall in pressure is therefore known and, as was indicated previously, the curve of the oil recovery *v.* percentage fall below the original saturation pressures (for the same stock tank oil and dome gas), the oil recovery by solution gas drive could be calculated for each period of production. (See example of this type of calculation, shown in Table II for oilfield No. I.)

The determination of the average original saturation pressure at the onset of gassing of the oil above the gas–oil level is complicated by the fact that the saturation pressure of the oil in different parts of the reservoir at any one time is not the same. Where the rock is frequently fissured the saturation pressure of the oil decreases rapidly towards the dome pressure because the diffusion path from rock matrix into fissures is small, and good convection in the fissures will rapidly transfer the gas to the dome. On the other hand, where the rock is not frequently fissured and convection is poor, the saturation pressure of the oil will remain near the original value before production started. The average value over each period was consequently obtained by volumetrically weighting the values for each part of the field.

TABLE II

Oilfield No. I—Solution Gas Drive in the Gas Dome
(See Fig 4 for Solution Gas Drive Performance)

Cumulative production time, years	Average original saturation pressure at onset of gassing, p.s.i.a.	Gas dome pressure at end of each period, p.s.i.a.	Fall in pressure, p.s.i.	% fall below average original saturation pressure	Theoretical solution gas drive % oil recovery
0	620	—	—	—	—
19	598	464	134	22·4	15·7
21	593	463	130	21·9	15·3
23	589	461	128	21·7	15·0
25	587	457	130	22·1	15·5
27	584	455	129	22·1	15·5
29	582	452	130	22·3	15·7
31	582	448	134	23·0	16·3
33	582	444	138	23·7	17·1
35	581	439	142	24·4	17·6
37	579	434	145	25·0	18·0
39	576	431	145	25·2	18·1
40·7	575	429	146	25·4	18·3
43·8	575	424·5	150·5	26·1	19·0

MATERIAL BALANCE METHOD OF CALCULATING OIL RECOVERY FROM THE GAS DOME

In the material balance method the gross volume of gas evolved in the reservoir which migrated to the gas dome was calculated for each production period. This gas volume can be made up of the expansion of an original gas cap, the gas released by solution gas drive on the oil originally in the gas dome, and the gas released from the oil below the gas–oil level due to the fall in its saturation pressure. Immediately below the gas–oil level there is a "gassing zone," but in the two oilfields considered here there was no migration of this gas into the gas dome, due to low gas saturation and consequently zero or very low permeability to gas.

The net gas volume in the dome was then equal to the gross volume minus the gas produced from the dome during the production period studied, and also minus any gas dissolved in surplus refinery products which have been recycled to these reservoirs.

The stock tank oil recovered from the gas dome was therefore equal to $\left[\frac{V}{B_{o,i}} - \frac{(V-G)}{B_{o,f}}\right]$

where V = original reservoir volumes of oil in gas dome;
G = net reservoir volumes of gas migrated into gas dome;
$B_{o,i}$ = initial formation volume factor of oil;
$B_{o,f}$ = formation volume factor of oil at the dome pressure at the end of production period considered.

The actual oil recovery efficiency from the gas dome was therefore equal to $100\left[1-\left(1-\frac{G}{V}\right)\cdot\frac{B_{o,i}}{B_{o,f}}\right]$ per cent of the original oil in the gas dome.

The stages of the calculation for oilfield No. I are shown in Table III.

TABLE III

Oilfield No. I—Material Balance Method of Calculating the Oil Recovery from the Gas Dome

Cumulative production time, in years	Formation volume factor of oil		Original reservoir oil in gas dome, $\times 10^6$ cu. ft. (V)	Gross volume gas evolved and migrated to gas dome, $\times 10^6$ cu. ft.	Net gas volume in gas dome, $\times 10^6$ cu. ft. (G)	% oil recovery from gas dome
	$B_{o,i}$	$B_{o,f}$				
19	1·111	1·099	75·8	27·91	13·82	17·3
21	1·111	1·099	102·7	33·18	18·26	16·9
23	1·111	1·099	128·4	39·65	23·83	17·7
25	1·111	1·098	145·1	45·00	28·03	18·3
27	1·111	1·098	164·5	50·00	31·72	18·3
29	1·111	1·098	178·3	54·39	34·70	18·5
31	1·111	1·097	182·9	58·17	36·88	19·1
33	1·111	1·097	191·0	61·78	38·74	19·2
35	1·111	1·096	200·1	65·87	41·60	19·6
37	1·111	1·096	213·7	70·71	44·36	19·6
39	1·111	1·096	231·4	73·92	45·96	18·7
40·7	1·111	1·095	237·5	76·76	48·13	19·1
43·8	1·111	1·095	230·4	80·77	48·52	19·8

Note: All volumes are under reservoir conditions.

TABLE IV

Oilfield No. II—Summarized Results for Oil Recovery from the Gas Dome by Solution Gas Drive and by Material Balance

Cumulative production time, in years	Original reservoir oil in gas dome, 10^6 cu. ft.	Fall in dome pressure, p.s.i.	Theoretical* solution gas drive % oil recovery	% oil recovery by material balance
11	24·6	141	4·5	33·0
16·8	74·6	212	6·9	20·3
22·7	145·4	260	8·4	16·4
25·8	115·3	230	7·5	19·8

* Mean original saturation pressure 1434 p.s.i.a.

The summarized results for oilfield No. II are shown in Table IV.

COMPARISON OF MATERIAL BALANCE AND SOLUTION GAS DRIVE RESULTS

(1) *Oilfield No. I*

A comparison of the last columns of Tables II and III shows that the actual oil recovery efficiencies from the gas dome are only 1 or 2 per cent higher than those calculated by solution gas drive. The contribution from gravity drainage is this difference between the two values, and in this case is only a small proportion of the recovery of oil from the gas dome.

The curves in Fig 4 show that the ultimate oil recovery by solution gas drive may be as high as 34 per cent. This extra 14 per cent (34–19·8) could be achieved by producing dome gas in order to reduce the pressure to, say, a final dome pressure of 75 p.s.i.a.

Incidentally it has been calculated that water drive had contributed only 14 per cent of the total oil produced up to the end of the period studied and that this efficiency was lower than that of solution gas drive. This accordingly suggests a policy of pressure depletion, if maximum oil recovery is the sole consideration.

(2) *Oilfield No. II*

A comparison of the last two columns of Table IV clearly shows that gravity drainage plays the major part in the oil recovery from the gas dome, since the actual recovery efficiencies are much greater than those predicted by solution gas drive alone.

Another point is also shown in the table. As the fall in dome pressure increases (the size of the gas cap increasing) the proportion from gravity drainage decreases. Therefore in this case, in order to get the maximum oil recovery from the gas dome, a policy of pressure maintenance could be recommended. Further pressure depletion would only decrease the average oil recovery from the gas dome.

DISCUSSION

The decision whether or not to maintain pressure by crestal gas injection into an oilfield must largely depend on the computed recovery by gravity drainage in the gas dome after several years of production life. Solution gas drive represents the least efficient oil recovery process and requires pressure depletion of the reservoir to achieve the maximum oil recovery.

The efficiency of gravity drainage depends largely on the rock permeability and to a smaller extent on the rate of oil production. In fissured limestone fields where the reservoir rock is several hundreds of feet thick, gravity drainage can occur vertically from the rock matrix into the fissures. In oilfield No. I the permeabilities of the oil-bearing limestone were very low, in the range 0·1–1 mD. In oilfield No. II the oil-bearing rock was more porous and had permeabilities in the range 1–10 mD. A further factor

which would widen the difference in the gravity drainage performance is the greater percentage fall in pressure below the original saturation pressure in oilfield No. I than in oilfield No. II; *i.e.* the higher gas saturations in No. I correspond to lower oil relative permeabilities and consequently lower gravity-drainage rates.

In many sandstone oilfields there is little opportunity for vertical gravity drainage because oil-bearing sands a few tens of feet thick are often separated by impermeable shales. In such cases drainage would tend to follow the direction of the bedding planes. For example, when the angle of dip is, say, 5°, gravity drainage rates equivalent to the case of the 1–10 mD limestone could be achieved only if the permeabilities were in the range 130–1300 mD. The relationship between vertical and horizontal permeabilities may be expressed approximately as $K_v = K_H \sin^2\alpha$, where α is the angle of dip.

ACKNOWLEDGMENT

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DEMERIT SYSTEM FOR RATING THE PERFORMANCE OF LUBRICATING OILS AND FUELS IN RECIPROCATING INTERNAL COMBUSTION ENGINES *

By R. TOURRET † (Associate Fellow) and R. W. BALE † (Associate Fellow)

WHEN an engine is stripped after operation and its components inspected in order to determine the performance of the lubricating oil and fuel, the amount of oil and fuel deterioration products, such as carbon, sludge, and lacquer, cannot be determined quantitatively by normal weighing or measuring techniques. In an attempt to place the assessment of these products on a quantitative basis, it has become the custom to use a demerit rating procedure in which the various thicknesses of deposits are given an arbitrary value, which when multiplied by the proportion of the area so covered, gives the demerit.

Unfortunately, no less than three methods were specified for the three types of engine already in use at the Admiralty Oil Laboratory (AOL) when it was proposed to bring into service a further type of engine for which nothing was laid down. The performance of lubricating oil in the Caterpillar 1A oil test engine was covered by IP 124/55 and in the Petter A.V.I. engine by the method suggested by Towle and Vaile.[1] The U.S. Navy had yet another method,[2] similar but not identical, which was used for rating both oil and fuel performance in all engines, both service and laboratory, including the Caterpillar 1A and the G.M.71 also used at AOL. No method was laid down for the Foden F.D.4 and other engines to be operated at AOL in the future.

It seemed desirable that one system should be used throughout at AOL. Ratings obtained on one type of engine could then be more fairly compared with ratings on another type. Such a system could be used for the Foden and any other engines to be operated at AOL, as well as for service engines. Since all three methods are basically similar, the unification appeared feasible.

Such considerations apply at other laboratories than AOL, and consequently it has been thought that it might be of interest to give details of the system proposed for use at AOL. The number of laboratories operating engines for the purposes of testing the performance of oils and fuels is increasing considerably at the present time. Many laboratories on the Continent are also being brought into commission, and many of these look to this country, and to the IP in particular, for a lead in technical matters. It seems an appropriate time, therefore, for the possibility of the adoption of a unified system for reporting engine deposits to be considered. With the end in view of establishing a national, if not international, system of rating such deposits, it is hoped that this paper will serve as a basis for written discussion.

Doubtless others with more experience of operating engines for oil and fuel testing can contribute by criticism, which will be welcomed if it helps to establish a uniform system available for general use.

IP 124/55 and the U.S. Navy use the demerit procedure in which a high rating denotes a bad oil performance, whereas the Petter method is a " merit " system in which a high rating denotes a good oil performance. This difference, incidentally, was one reason why a unified system appeared to be desirable at AOL.

Right at the start the choice had to be made between the two. The demerit system appeared to be the most logical, since in all cases it was the amount of deterioration product that was being assessed. Indeed, merits are generally estimated in the Petter merit system by first assessing demerits and then subtracting from the possible maximum value. This appeared to involve unnecessary labour, besides confusing the issue to some extent, since laboratories are concerned with the amount of deterioration products rather than the amount of clean areas. The award of ten " marks " out of ten given by the merit system may have some appeal to those with commercial considerations in mind, but it is considered that a rating system is basically intended for technical use, and technical requirements should have precedence.

The Petter system also differed from the other two in that some ratings were weighted and that the sum of the weighted ratings was taken as the general index of the performance of an oil. The weighting procedure, in which some merits were given a greater weight than others by multiplying by given factors, may be desirable for a particular type of engine in which, for instance, the relative importance of sludge and lacquer or carbon and lacquer may be known. In general, however, it seems that the relative importance of different types of deposit on different components would vary from one type of engine to another. Possibly the relative importance of different types of deposit would also vary from one type of oil or fuel to another. For these reasons it seemed preferable to rate all deposits on all components uniformly (in fact using ten as a maximum), leaving any assessment of the relative importance of the

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different ratings open to consideration for individual cases.

It was decided, therefore, that all demerit ratings should range from 0 for completely clean to 10 for the worst possible condition. A high demerit, therefore, denotes a bad oil performance. Since all demerits depend on an operator's individual assessment, high accuracy cannot be expected, and it seems reasonable to follow the custom that demerits should be reported to the nearest 0·1 only. Any slight deposit less than 0·05 demerit should be reported as " trace," and the use of " trace " should be restricted as here defined.

Carbon, lacquer, and sludge are defined in the Appendix, together with other terms. When sludge has to be removed to rate the component for carbon or lacquer, it is generally specified that the component be wiped with a clean rag soaked in kerosine. This procedure, however, is difficult to define because type of cloth, pressure, time, etc., may vary. A more easily defined procedure would be to dip the component in light petroleum spirit such as SBP2 or SBP3, but this does not remove all the sludge. A fair compromise seems to be to specify that such components should be dipped in SBP2 or SBP3 and brushed with a small camel-hair brush to remove sludge.

This present note is an attempt to draft one method suitable for rating the performance of lubricating oil and fuel in all types of engine in the simplest form, using the best features from the three existing methods. In a few instances it was considered that the existing methods could be improved and a new one is proposed. The method of cleaning to remove sludge is an instance of this.

In general, components are rated by assessing the proportion of the area covered with deposit from 0 for no deposit to 10 for the area completely covered, and multiplying by a factor depending on the colour or depth of deposit from 0 for no deposit for 1·0 for the maximum possible. This gives a demerit ranging from 0 for the best possible condition to 10 for the worst possible condition. For each item, the average for the whole engine should be reported.

The multiplying factors for depth, thickness, and colour are used frequently and, in the system proposed here, the same multiplying factors are used for all components. This is not always so in the other systems.

The items to be included will vary to some extent according to the particular design of engine in which the performance of the lubricating oil or fuel is to be rated, but all items applicable to that design of engine should be recorded. Some items will be mainly applicable to lubricating oil performance, some to fuel oil, and some to both.

The various items to be rated are considered in turn below. On the left hand side is the proposed method and on the right hand side comments on why the method was chosen, how it differs from existing methods, etc. Wear of components is not included, since measurements can be made directly on a quantitative basis.

Proposed Method

(1) *Piston Ring Sticking*

Rate the ring sticking when the piston is cold for each of the rings according to Table I.

Table I

Condition		Demerit
Free		0
Sluggish		0·5
Pinched :	0–75°	1
	75–150°	2
	150–225°	3
	225–300°	4
	300–360°	5
Stuck :	0–75°	6
	75–150°	7
	150–225°	8
	225–300°	9
	300–360°	10

(2) *Ring Groove Carbon*

Estimate for each ring groove the proportion of the clearance volume between the ring and the back of the groove which contains carbon (not lacquer). This may conveniently be assessed by averaging the volume blocked at, say, twenty equally spaced stations round the periphery of the groove. For example, if 28 per cent of the clearance volume is blocked with carbon, the demerit would be 2·8.

Comments

This rating follows that employed by the U.S. Navy. This is preferred to the systems employed on the Caterpillar and the Petter because distinction is made between pinched and stuck rings (or cold stuck and hot stuck). These two systems are not identical, but in both cases a ring which is only just stuck, say 30°, is given a low demerit (4 in the Caterpillar and 3 in the Petter), whereas a higher demerit (6 in the U.S. Navy method) seems justified.

This method follows that generally employed by most laboratories. All three methods use a thickness factor for multiplying the proportion of the area covered to give a demerit, but it seems that in many cases the depth can be assessed directly if a gauge is made to indicate the full clearance volume. The U.S. Navy and Caterpillar methods employ an additional multiplier according to the type of deposit. However,

Proposed Method	Comments
	it is considered that sludge would be easily washed out in operation and should be neglected in the rating, *i.e.* the piston cleaned of sludge before assessment. Lacquer in the grooves, on the other hand, is considered sufficiently important to merit an attempt at separate rating. The merging of lacquer and carbon into a single rating (as in the U.S. Navy and Caterpillar methods) means that information is lost and that some fixed and probably arbitrary balance between the relative importance of carbon and lacquer is struck. Since the relative importance of carbon and lacquer is liable to vary from one design of engine to another, it is considered that an attempt should be made to rate them separately.
(3) *Ring Groove Lacquer–Carbon* Estimate the proportion of the area of the back of each ring groove that is covered with lacquer or carbon and multiply by the appropriate colour factor shown in Table II. Areas covered by carbon should be rated as if covered with black lacquer.	This is an attempt to rate lacquer in the ring grooves, allowing for the possible presence of carbon deposits.

Table II

Discoloration	Colour factor
Clean	0
Light brown	0·25
Medium brown	0·5
Dark brown	0·75
Black	1·0

In those cases when carbon is present, estimate the proportion of the area of the groove that is covered with carbon only and multiply by 1·0.

The ring groove "lacquer" deposit demerit should be reported followed by the carbon figure in parenthesis, *e.g.* "7·8 (6·0)," so that it is immediately apparent if the presence of carbon has raised the true lacquer deposit demerit.

(4) *Oil Control Ring Deposits* Estimate the proportion of the area of the slots or holes which is blocked by carbon or sludge for each oil control ring. For example, if a quarter of the area of the slots is blocked, then the demerit is 2·5.	Equivalent to all three methods.
(5) *Crown Land Deposits* Estimate the proportion of the area of the land which is covered by carbon or lacquer and multiply by the appropriate thickness factor shown in Table III. Scuffed and cut areas should be rated as if completely covered with heavy deposit.	Equivalent to the Caterpillar and U.S. Navy methods, except that sludge is ignored. Equivalent to the Petter method except that the depth factors are slightly different.

Table III

Thickness or depth	Thickness or depth factor
None	0
Light	0·25
Moderate	0·5
Moderately heavy	0·75
Heavy	1·0

Proposed Method	Comments
(6) *Piston Land Lacquer* Estimate the proportion of the area of the piston lands which is covered with lacquer and multiply by the appropriate colour factor shown in Table II. For example, if 30 per cent of the area is light brown and 10 per cent black, the demerit rating would be $(3 \times 0{\cdot}25) + (1 \times 1)$, giving a demerit of 1·8.	Equivalent to the Petter method. The U.S. Navy method considers sludge, which is not thought important, as well as rating the lands on a depth rather than colour basis. It is considered that colour is a better basis, since this is more accurately estimated than depth. The Caterpillar method is the same as the U.S. Navy method except that the depth is not considered.
(7) *Piston Skirt Lacquer* Estimate the proportion of the area of the piston skirt which is covered with lacquer and multiply by the appropriate colour factor shown in Table II.	Equivalent to all three methods.
(8) *Piston Interior Lacquer* Estimate the proportion of the area of the inside of the piston (both crown and walls) which is covered in lacquer and multiply by the appropriate colour factor shown in Table II.	A new item. It is considered that lacquer on the inside of the piston may give some indication of the resistance of an oil to high temperatures.
(9) *Piston Crown Land Cutting* Estimate the proportion of the area which is cut and multiply by the depth factor shown in Table III.	Similar to all three methods. The U.S. Navy and Caterpillar methods distinguish merely between "light" and "deep," and the Petter method includes only one other grade, "moderate." The use of Table III provides a wider range of degrees of cutting, as well as eliminating the need for two different tables of depth factors.
(10) *Cylinder Bore or Liner Lacquer* Estimate the proportion of the area swept by the compression rings which is covered by lacquer or carbon, and multiply by the appropriate colour factor shown in Table II.	Equivalent to the Caterpillar and U.S. Navy methods. This item is not considered in the Petter method.
(11) *Cylinder Head Deposits* Estimate the proportion of the area of that part of the cylinder head exposed to combustion which is covered by deposits, and multiply by the appropriate thickness factor shown in Table III.	Not considered in any of the three methods, but similar to the method understood to be employed by the U.S. Navy in future except that the hardness of the deposit is not considered.
(12) *Inlet Port Restriction* Estimate the proportion of the area of the parts which is restricted by carbon or other deposits. For example, a third blockage would warrant a demerit of 3·3.	The U.S. Navy method gives a demerit of 10 for 50 per cent blockage. While this emphasizes the practical importance of blockage, it does not permit the rating of blockages in excess of 50 per cent. Accordingly, in the scheme proposed the demerit is proportional to the degree of blockage. The Caterpillar and Petter methods naturally do not consider port blocking.
(13) *Exhaust Port Restriction* Estimate the proportion of the ports which is restricted by carbon or other deposits.	See comment on (12).

Proposed Method	Comments
(14) *Valve Deposits* Estimate the proportion of the areas of (*a*) the stem; (*b*) the neck; (*c*) the seat face; and (*d*) the head of the valves, which are covered by deposits (not sludge) and multiply by the appropriate thickness factor shown in Table III. Report the average demerit for the whole engine separately for each part of the valve.	Not considered in any of the three methods but similar to a method understood to be used by the U.S. Navy in future, except that the hardness of the deposit is not considered.
(15) *Valve Sticking* Rate the valve sticking for each valve as shown in Table IV.	Not considered by any of the three methods, but similar to a method understood to be used by the U.S. Navy in future.

Table IV

Condition	Demerit
Free	0
Sluggish	5
Stuck	10

Report the average demerit for all valves, including both inlet and exhaust, for the whole engine.

(16) *Valve Seat and Face Condition* Rate the valve seat and face separately for each valve as shown in Table V.	Not considered by any of the three methods, but similar to a method understood to be used by the U.S. Navy in future.

Table V

Condition		Demerit
Clean		0
Pitted		1
Indented		2
Blow-by:	0–60°	3
	60–120°	4
	120–180°	5
	180–240°	6
	240–300°	7
	300–360°	8
Burned		10

Report the average demerit for all valves, including both inlet and exhaust, for the whole engine.

(17) *General Components Sludge* The components to be rated will vary according to the particular design of engine in which the performance of the lubricating oil and fuel is to be rated. Typical components are push-rod chamber and cover plate, rocker arm components and cover plate, oil screen, oil sump, and timing gears and case. Estimate the proportion of the area of each component which is covered with sludge and multiply by the appropriate thickness factor shown in Table III. Report the average demerit for the whole engine for each component separately.	Similar to the Petter and U.S. Navy methods. Not considered by the Caterpillar method.

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APPENDIX

The following terminology is to be used for describing and evaluating :

Free Ring—A ring which will fall of its own weight when its plane is moved from the horizontal to the vertical.

Sluggish Ring—A ring which will not fall of its own weight when its plane is moved from the horizontal to the vertical, but which will move under moderate finger pressure.

Pinched Ring—A ring which will not move in its groove under moderate finger pressure, but which has a bright, polished face over its entire circumference showing that it was free during engine operation.

Stuck Ring—A ring which will not move under moderate finger pressure and whose face is covered with lacquer or carbon over parts of its circumference showing that the ring was not bearing against the cylinder wall during engine operation.

Top Land Carbon Cutting—Abrasion of the area above the top ring as a result of excessive build-up of hard carbon on the liner or of the passage of hard carbon between the liner and the piston. The abrasions may appear as wide lines or grooves, plastic deformation of the surface, or as scuffing.

Sludge—A black, mud-like mixture of oil, carbon, and sometimes water, with or without foreign material. It is not sticky and has little adhesive properties. It can be removed by dipping in SBP2 or SBP3 and brushing lightly.

Lacquer—A hard, dry, lustrous, oily, insoluble deposit which cannot be removed by dipping the component in SBP2 or SBP3.

Carbon—A black morphous deposit normally without lustre.

Valve Stem—The straight portion of the valve that rides in the valve guide.

Valve Neck—The curved portion of the valve that exists from the valve face to the stem.

Valve Face—The portion of the valve that makes contact with the valve seat in the cylinder head.

Valve Head—The portion of the valve situated in the combustion chamber.

Free Valve—A valve which is easily removed from its guide.

Sluggish Valve—A valve which can only be removed from its guide under hand pressure.

Stuck Valve—A valve which cannot be removed from its guide under hand pressure.

EFFECT OF USING SILICONES IN THE LABORATORY TEST FOR RECOVERING BITUMENS AND IN THE DISTILLATION TEST FOR CUTBACK BITUMENS *

By E. H. GREEN †

SUMMARY

It is shown that the use of silicone grease for stop-cock lubrication in IP 105 or of silicone anti-foam in IP 27 causes the penetration of the recovered or residual bitumen to be significantly increased. An explanation of this effect is suggested.

INTRODUCTION

THE ground-glass joints of apparatus used for the recovery of bitumen from bituminous road mixtures have recently been lubricated with a silicone stop-cock grease to prevent the joints from binding at high temperatures. It was suspected that bitumens were being recovered soft, and check tests showed that a 200-pen bitumen, for instance, became 250-pen bitumen after recovery. This was found using both the Road Research Laboratory comprehensive method [1] and the standard method,[2, 3] although strict conformity to the specified conditions of test was observed. The softening was not, however, ascribed to the presence of silicone grease until the following evidence was found.

It had occasionally been found impossible to carry out a standard distillation test on a cutback bitumen, or more frequently on a tar, due to excessive foaming, caused usually by moisture present in the sample. 0·01 per cent of silicone anti-foaming agent added to the binder enabled distillations to be carried out, but the bitumen residues were invariably soft when a silicone fluid was present. A similar effect has been reported by other workers.[4–6] This suggested a possible reason why bitumens were being recovered soft; investigations showed that the silicone grease used on the ground-glass joints was responsible for the effect.

EFFECT OF SILICONES ON THE RECOVERY OF BITUMEN

Seven bitumens covering the range employed in road construction (60–330 pen) were recovered, using two identical sets of apparatus, one being built entirely from new glass with petroleum jelly on the joints, the other having silicone grease. Both the standard method and Road Research Laboratory method were used, and in all some twenty pairs of determinations were made. Bitumens recovered in the apparatus on which the silicone grease was used were invariably softer and the penetrations were generally 20 to 30 per cent higher than the original penetrations.

It was concluded that silicone grease was responsible for the softening of bitumen during recovery, and it should not, therefore, be used in the recovery apparatus. It can be removed from glassware by thorough washing with kerosine followed by chromic–sulphuric acid cleaning mixture.

EFFECT OF SILICONES ON THE CUTBACK BITUMEN DISTILLATION TEST

As mentioned previously, the effect of silicones in softening bitumen was first noticed while carrying out distillation tests on cutback bitumens according to method IP 27/53,[7] in the presence of 0·01 per cent of a proprietary silicone anti-foaming agent. A further series of tests confirmed that the residual bitumen was invariably soft if a silicone product had been used during the distillation.

The amount of oil distilled was entirely unaffected by silicone and cannot account for any differences in the distillation residues. The differences must therefore be due to the presence of the silicone. This was confirmed by distilling a cutback bitumen without silicone; the residue was poured into two tins, one containing 0·01 per cent of silicone and the other none. The bitumen which cooled without any silicone had a penetration of 130, compared with 170 for the sample containing silicone. This is due, as is shown later, to a greater loss of oil from the open tin which contains no silicone.

EXPLANATION OF SOFTENING

Two explanations of this effect are possible. The silicone may have an effect on the air–liquid interface and may therefore affect the evaporation of solvent, or it may affect the physical structure of the bitumen.

These possibilities were investigated by carrying out loss-on-heating experiments on cutback bitumens, with and without added silicone. At the standard temperature 163° C and also at 240° C there was, unexpectedly, a slightly greater loss from the samples containing silicone than from the control samples without silicone. At 360° C the effect was reversed and

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silicone definitely retarded the loss of flux oil. Typical results are shown in Table I, where all the cutbacks were prepared from the same 100-pen bitumen, P indicating the addition of a petroleum-base flux oil and T a tar-base flux oil; 0·1 per cent of a silicone anti-foaming agent was added to the appropriate samples.

TABLE I

Effect of Silicone on Loss-on-heating Test

	2½ hr at 240° C		10 min at 360° C	
	Without silicone	With silicone	Without silicone	With silicone
Sample P, % loss	5·5	5·55	4·5	2·3
Sample T, % loss	5·9	6·7	6·2	2·8
Sample P.1, % loss	—	—	6·8	5·3
pen of residue (15° C) *	—	—	50	75
Sample T.1, % loss	—	—	9·1	4·1
pen of residue (15° C)	—	—	58	133

* Penetrations after loss-on-heating tests were carried out at 15° C because there was insufficient depth in some cases for testing at 25° C.

Further tests were carried out to examine the direct effect of the addition of silicone on the consistency of bitumens. Residual bitumens were heated with silicone at temperatures up to 360° C. No changes in penetration, compared with the control samples without silicone, were recorded.

Ring and ball tests were carried out, one ring being placed on an amalgamated brass plate whilst the other was placed on a brass plate treated with silicone grease. No differences in softening points were found.

These tests indicate that the silicones used in this investigation have no effect on the physical structure of bitumen, but that they retard the evaporation of oils from the surface of bitumen at high temperatures. In the distillation test for cutback bitumens, the residue at 360° C is poured into an open tin to cool. Under normal conditions there is considerable evaporation of oils which is retarded when a silicone is present, giving a softer residual bitumen.

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[7] "Standard Methods for Testing Petroleum and its Products." Method IP 27/53. London: Institute of Petroleum, 1953.

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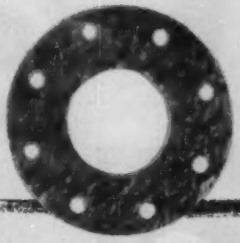

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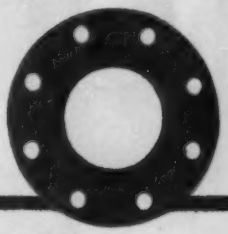

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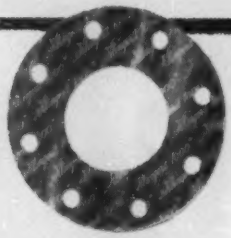

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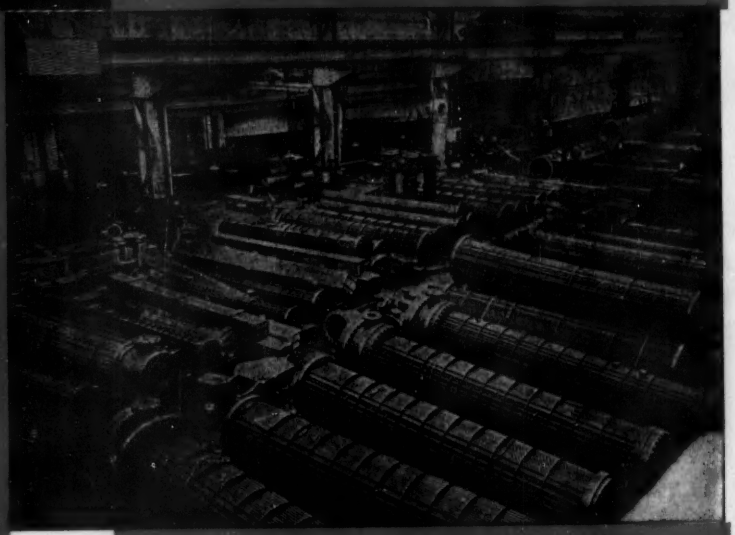

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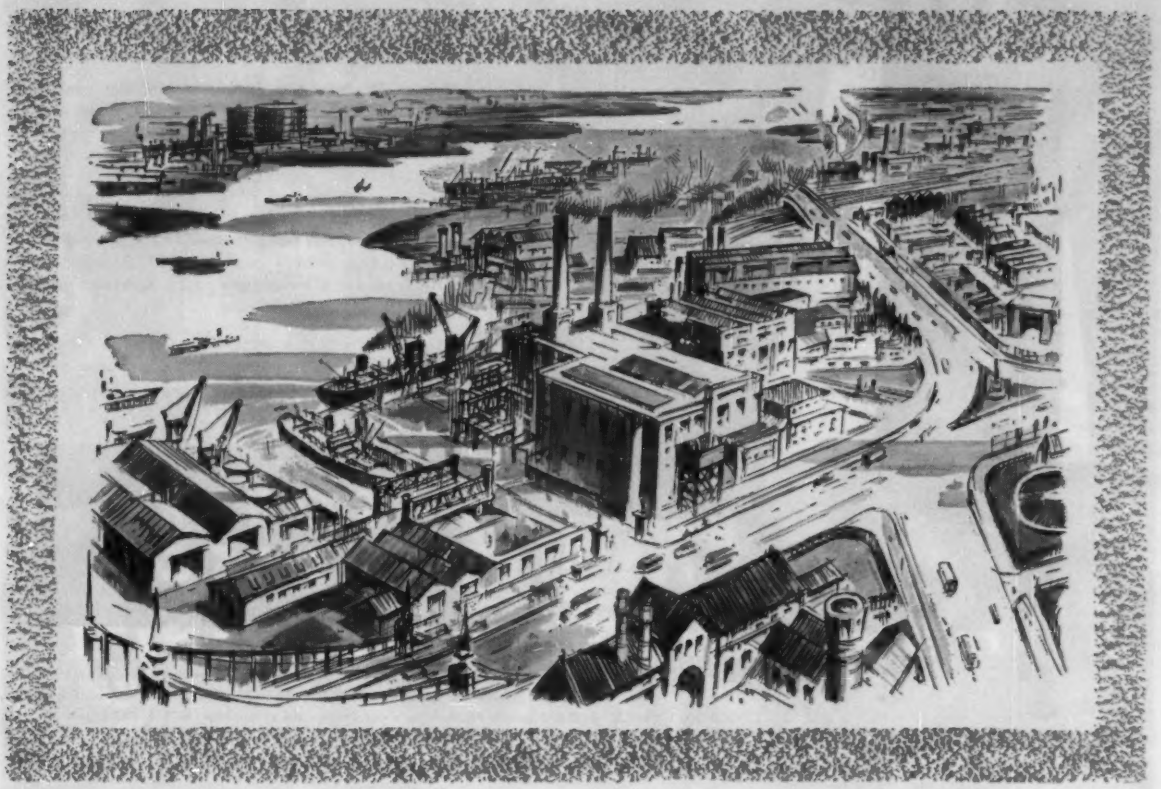

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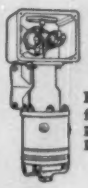

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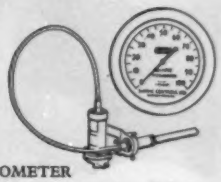

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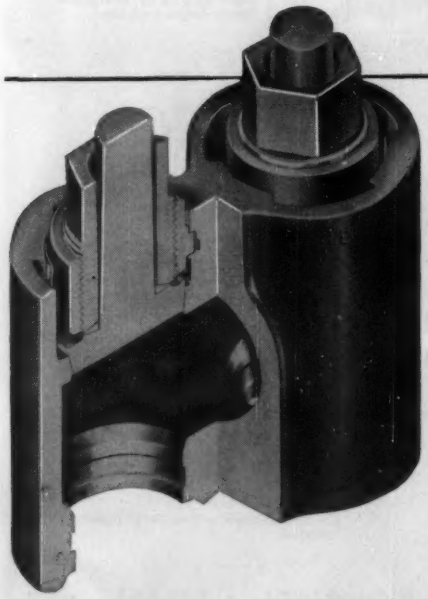

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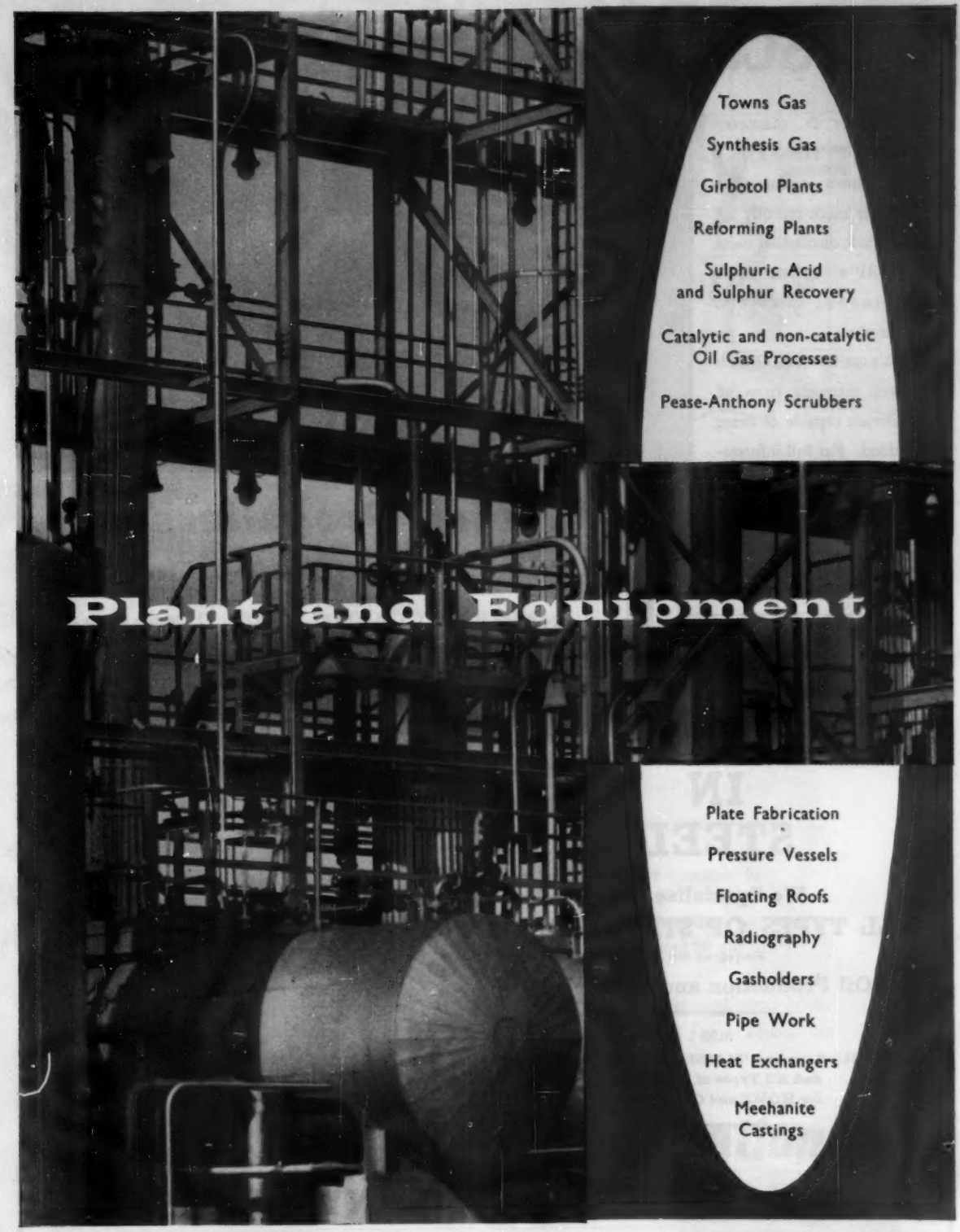

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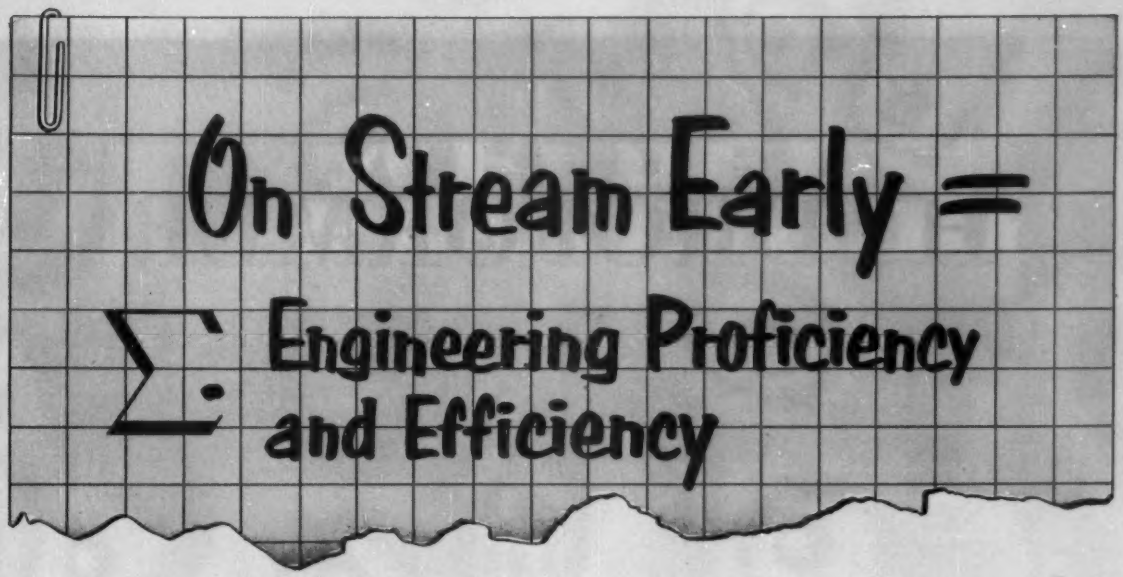

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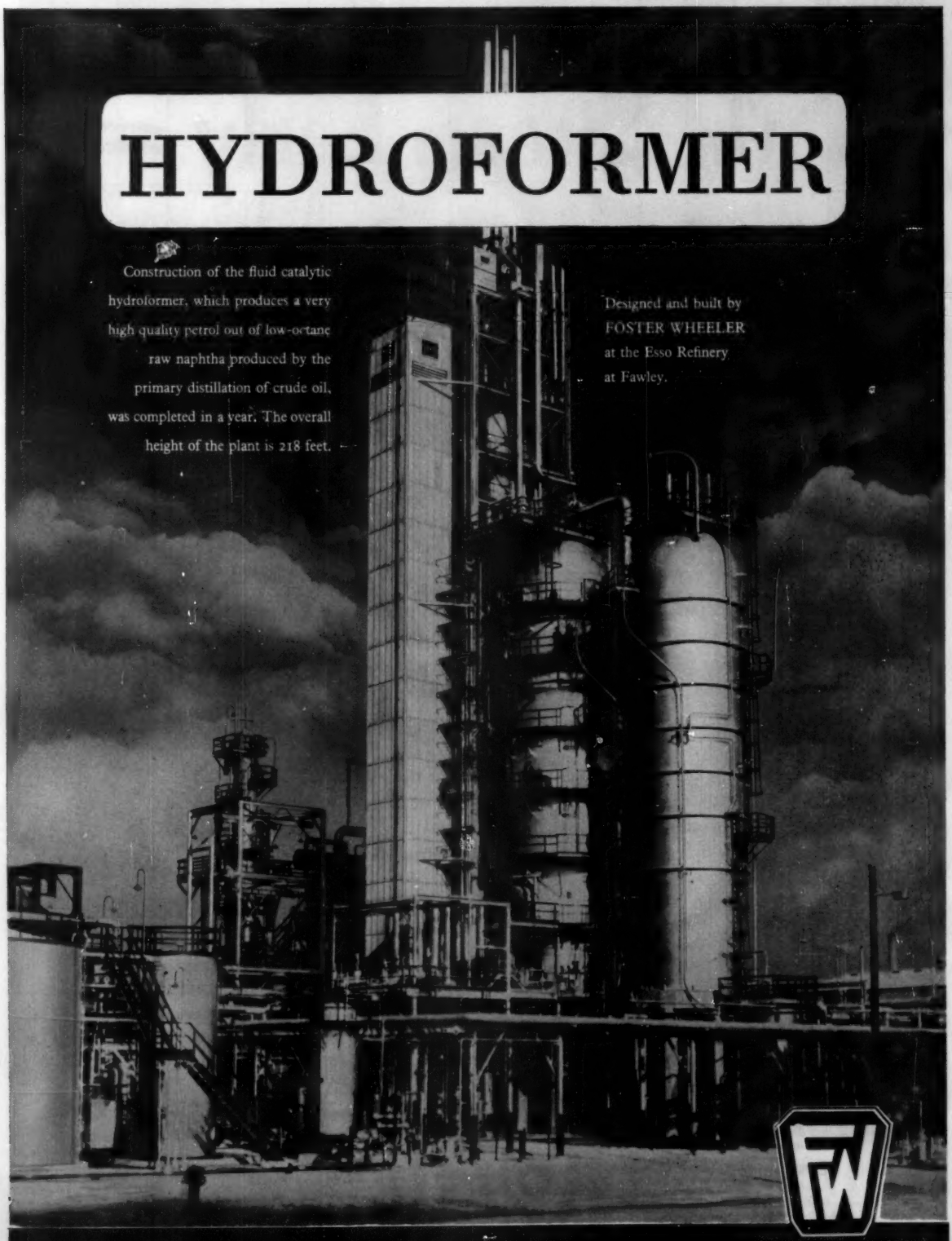

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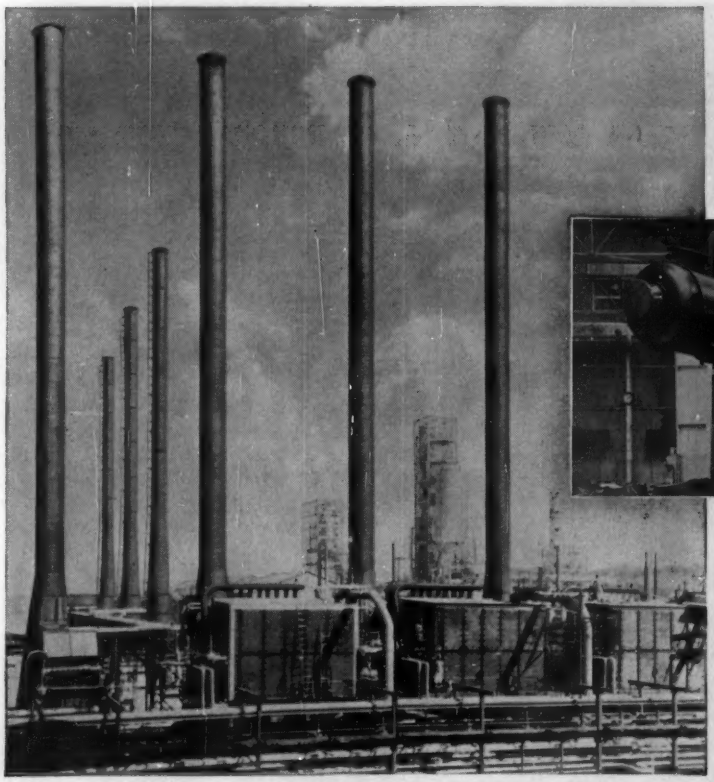
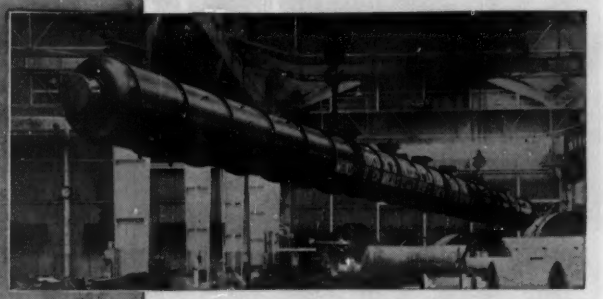


(left)
Babcock oil-fired boiler plant at Burmah-Shell refinery, Trombay, India.



(above)
Babcock fusion-welded treating tower for a Scottish chemical plant.

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THE complete outdoor boiler installation (above) at the Burmah-Shell Refinery, Trombay, with its oil-fired boiler plant, separately-fired superheater and steel, self-supporting chimneys, all manufactured and installed by Babcock & Wilcox; and the 110′ long x 4′ 6″ i.d. topping tower (right) — one of a number of Babcock fusion-welded pressure vessels for a chemical plant in Scotland, are an indication of the wide range and world-wide service offered by BABCOCK to the oil and chemical industries. This service includes the design, manufacture and installation of all kinds of water-tube boilers, oil-fired "packaged" boilers, and waste-heat boilers, heat-exchangers and separately-fired superheaters for very high temperatures; also jib and travelling cranes, conveyors and other mechanical handling plant.

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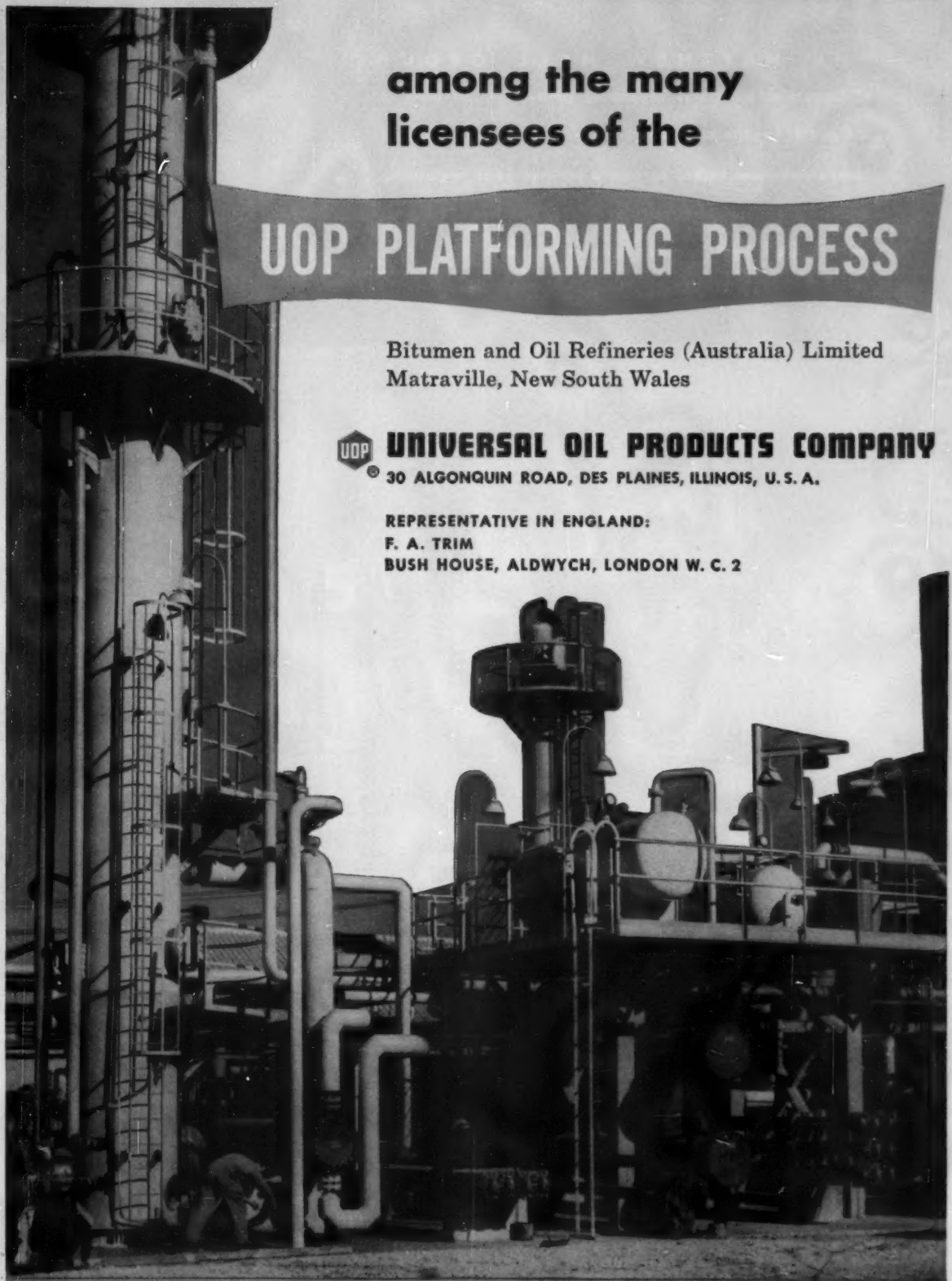

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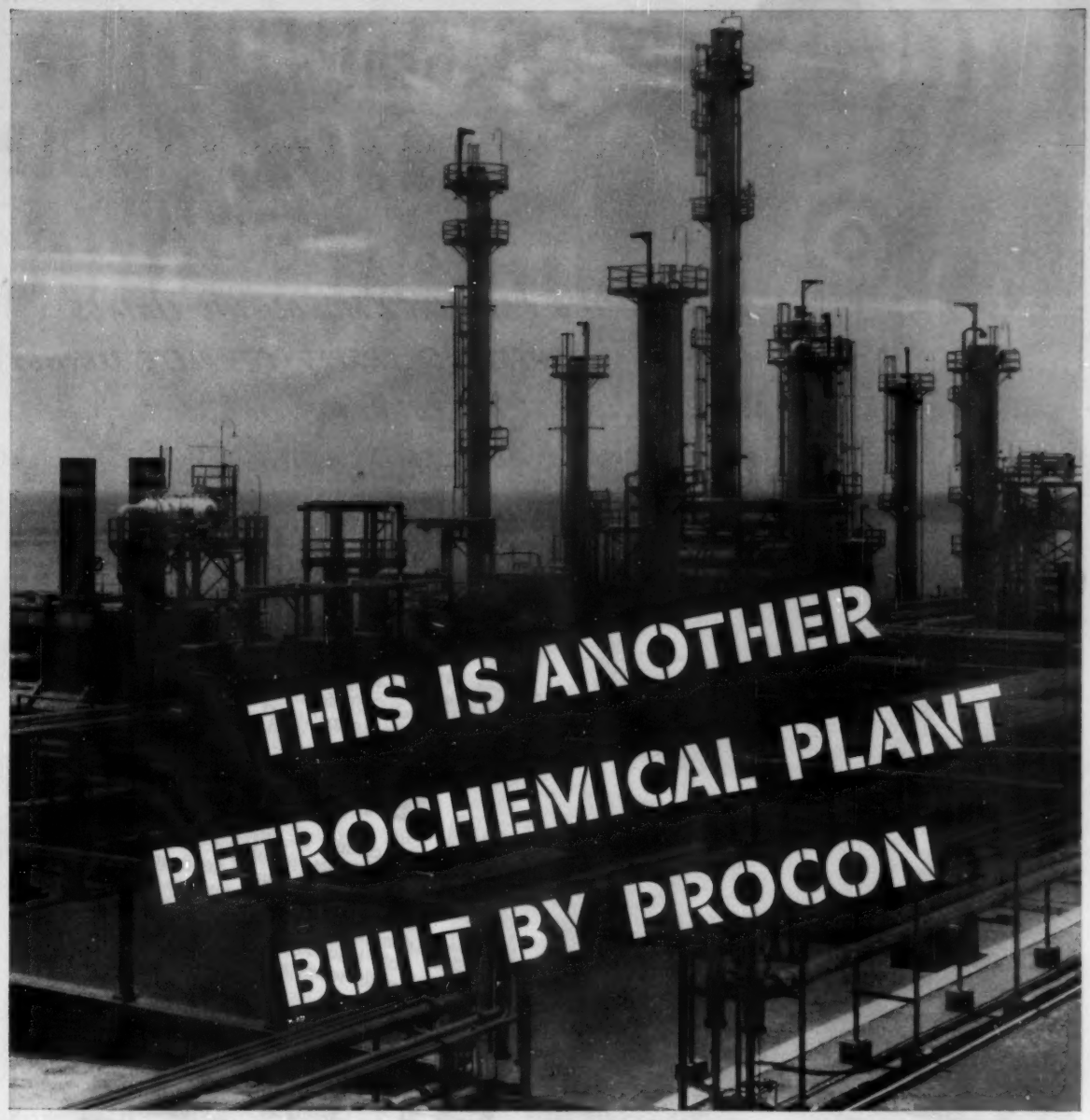

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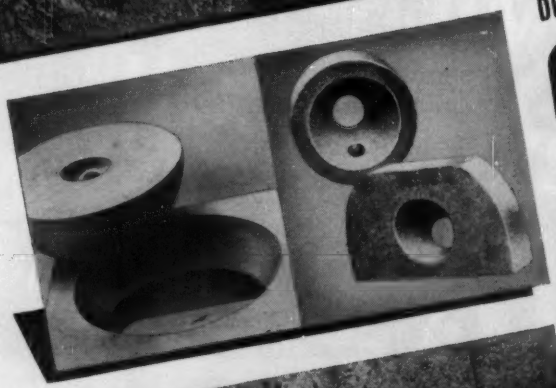

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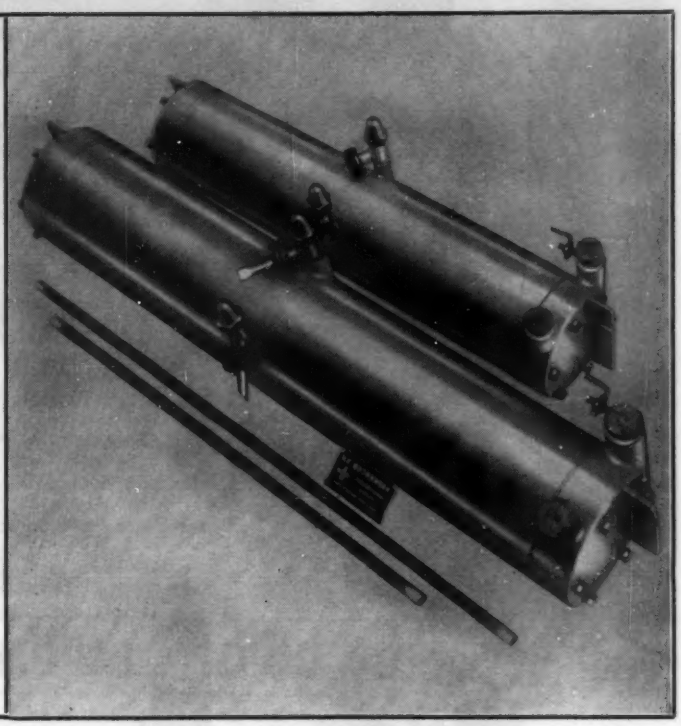

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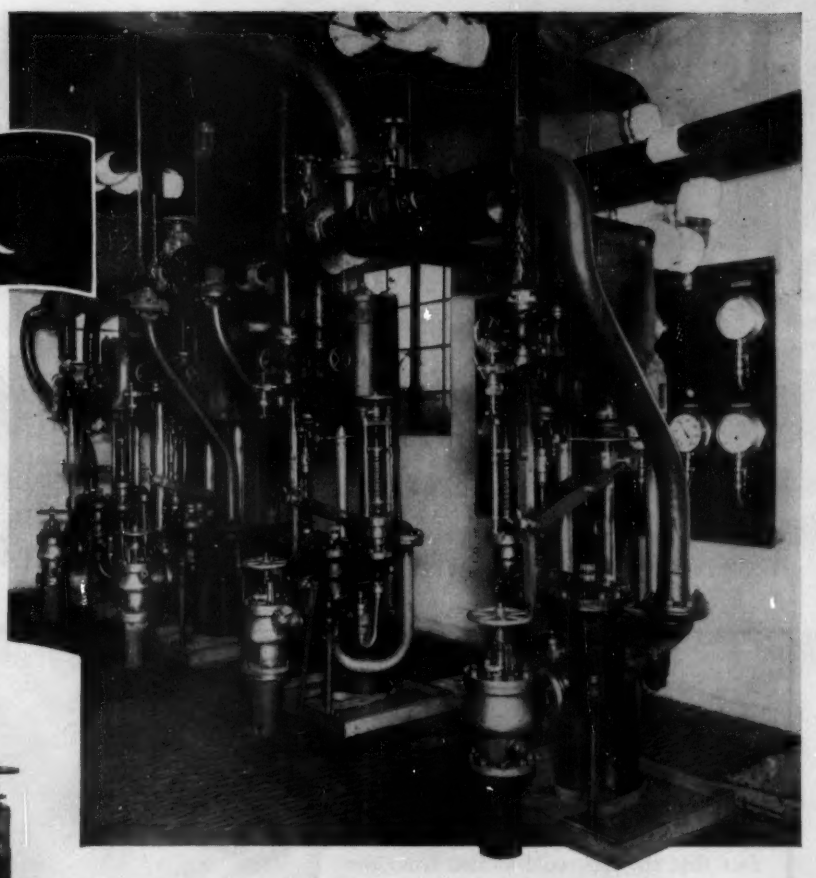

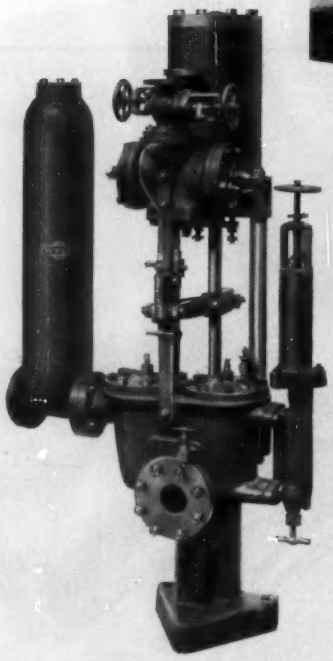

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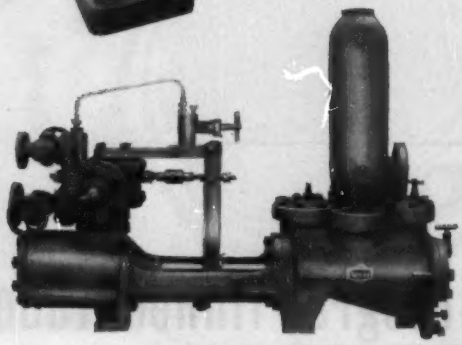

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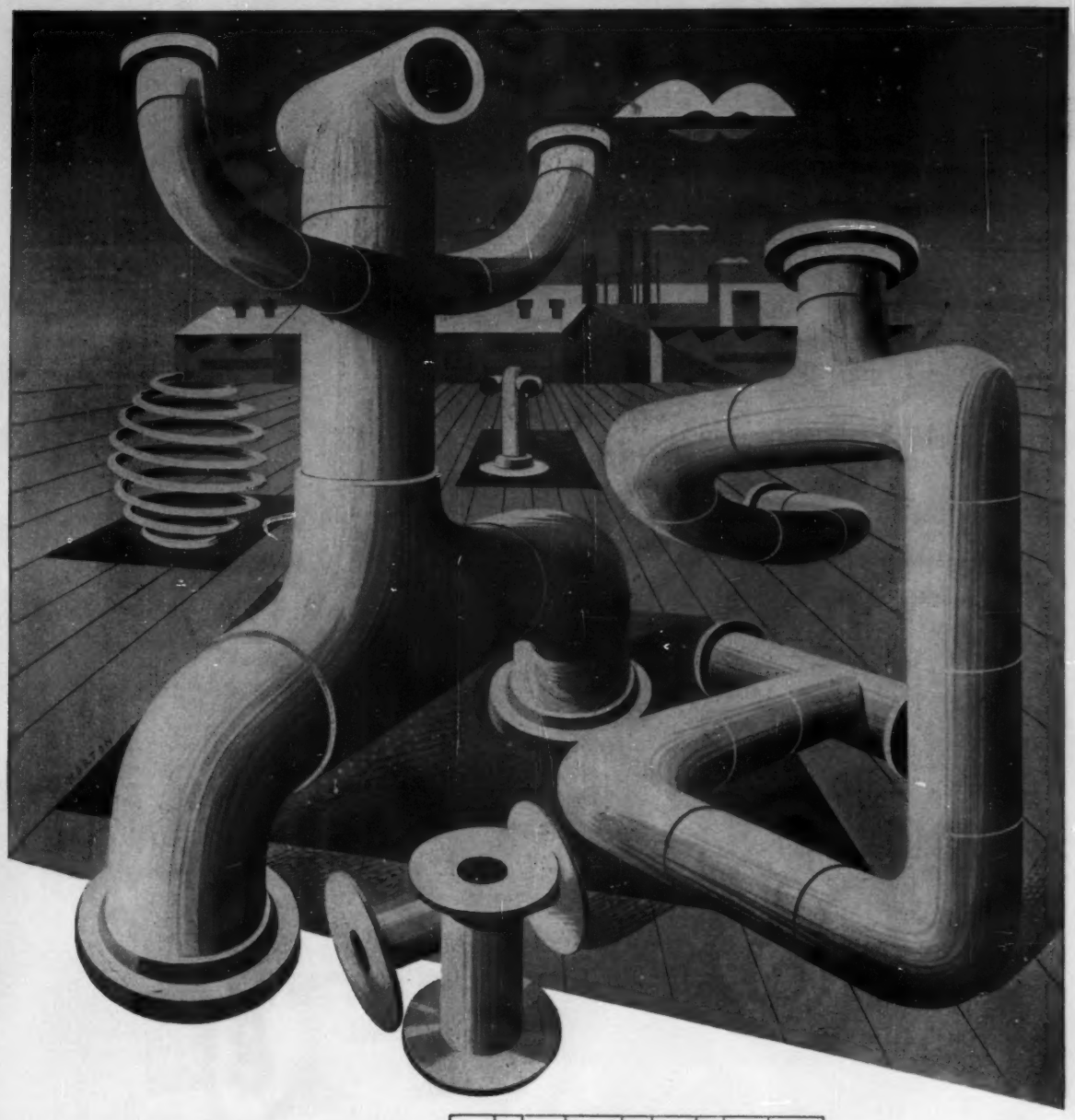

for any shape or size in **aluminium** *and its alloys*

Consult MARSTON EXCELSIOR

Aluminium alloy piping can be fabricated up to any size in diameter and approximately 1″ thick. The existing range of Marston Excelsior products varies from small, relatively thin-gauge items weighing less than 1 lb. to large plant vessels over 50 ft. long involving material thickness up to 4 in. and weighing nearly 10 tons.

Marston Excelsior also specialize in

★ *Flexible Tanks.*
★ *Radiators and Heat Exchangers.*
★ *Laminated Plastic Components.*
★ *Specialized Engineering Assemblies.*

MARSTON EXCELSIOR LIMITED • FORDHOUSES • WOLVERHAMPTON

(A subsidiary company of Imperial Chemical Industries Limited)

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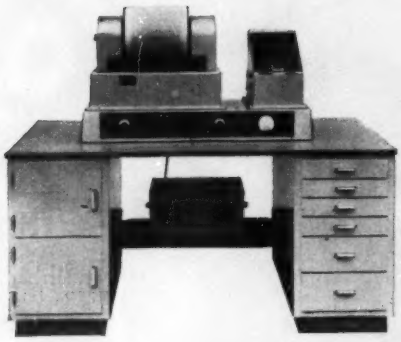
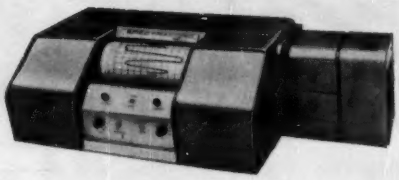


Model 21

The Perkin-Elmer Model 21 infrared Spectrophotometer is one of the outstanding analytical tools of the infrared field. Designed to provide both high quality survey spectra and precise routine quantitive data, the Model 21's full capabilities are there when needed. A continuing programme of instrument improvement and development assures the position of Model 21.

Accurate and precise, it offers complete flexibility in resolution, spectral presentation and recording speeds (with single switch automatic control, once operating conditions are chosen). A complete range of accessories extends its versatility.

The Model 4000 recording UV Spectrophotometer features a double monochromator with high resolution. Stray light is practically eliminated. It covers visual, near IR and UV. Being a double beam instrument, it records in transmittance or absorbance. Model 3000 recording attachments convert standard single monochromators into versatile recording spectrophotometers.



Model 4000

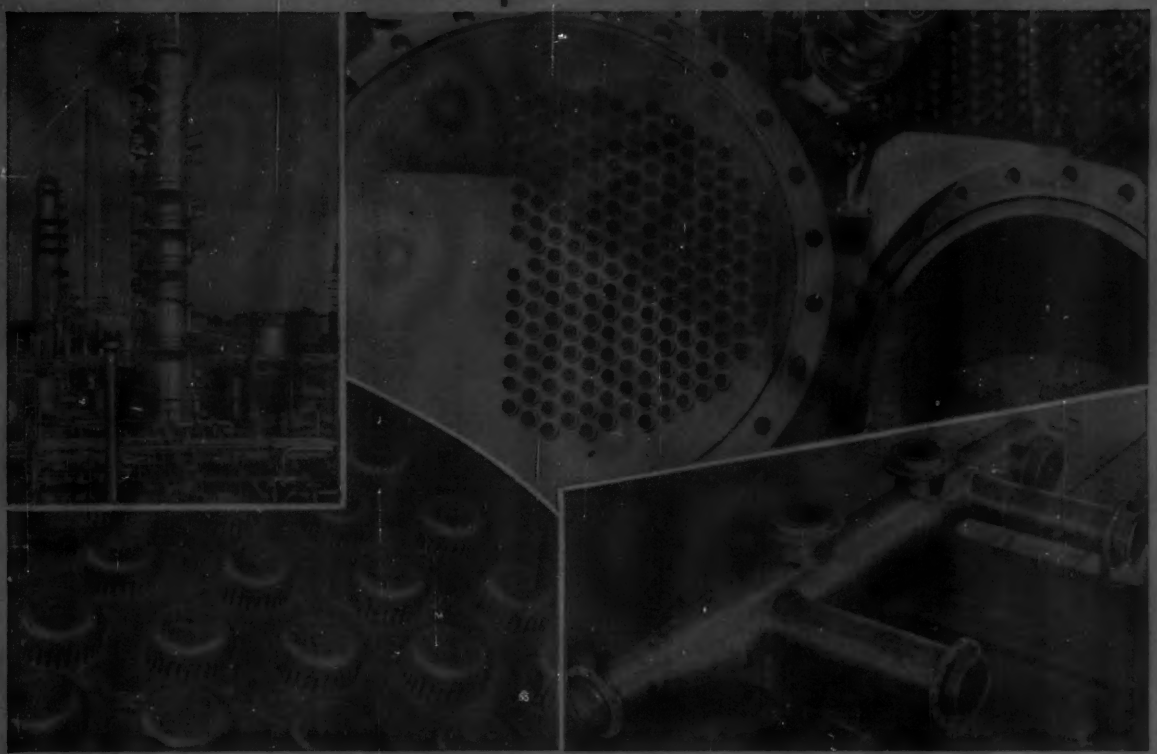
For enquiries please write to:

PERKIN-ELMER AG,

SONNEGGSTRASSE 30, ZURICH, SWITZERLAND

TO COUNTER CORROSION

NICKEL alloys



Corrosion in petroleum refining is high on the list of factors which lead to costly maintenance. Corrosion problems are encountered in operations such as caustic stripping, gasoline distillation, the cracking of residues and alkylation processes. In each case the corrosion problems encountered require careful consideration before a satisfactory solution is found and, in consequence, many materials are incorporated in refinery equipment.

The use of nickel and nickel-base alloys has greatly assisted the refinery engineer in meeting many of his problems and consequently, their uses in the refinery are both varied and numerous. The mechanical properties of these alloys, coupled with an appropriate resistance to attack under exacting conditions, have increased the working life and the efficiency of refinery equipment and have avoided frequent and costly "shut-down" periods.

Wiggin nickel alloys are also responsible for increased efficiency in many industrial processes which involve either severe corrosive or high temperature conditions.

NICKEL Wrought nickel combines good mechanical properties with a high degree of resistance to a wide variety of corrosive conditions.

MONEL An alloy of nickel and copper with small percentages of manganese and iron, Monel resists attack by many organic and inorganic acids, alkalis and salts in numerous industrial applications.

INCONEL A nickel-chromium alloy with a small controlled amount of iron, Inconel offers resistance to oxidising atmospheres at high temperature and to certain of the forms of corrosive attack experienced in the process industries.

Publications containing the fullest technical information on these materials will gladly be sent on request.

OUR TECHNICAL SERVICE

is available to assist those with problems involving corrosion at high temperatures.

'Monel' and 'Inconel' are Registered Trade Marks.

HENRY WIGGIN & COMPANY LIMITED *WIGGIN STREET · BIRMINGHAM 16*